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Contents

Sustainable Architectural Design

389 **Transfer of Ultrafine Particles and Air in Multi-storey Buildings**
Amalie Gunner, Siamak Rahimi Ardkapan, Alireza Afshari and Niels Christian Bergsøe

395 **Teaching Sustainability in Design without Greenwashing**
Ulrike Heine

405 **Fuel Poverty and Comfort in Modern Residential Apartments in Developing Countries: A Case from Jordan**
Nabeel AlKurdi and Abdulsalam A. Alshboul

413 **Faults and Claims about Thermal Environments in Relation to Energy Saving Measures in Smaller Office Buildings**
Noriko Umemiya, Taiji Obuchi and Ryota Matsui

Infrastructure and Environmental Engineering

425 **Experimental Verification to Estimate Ground Thermal Conductivity Using Spiral Coil Type Ground Heat Exchangers**
Seok Yoon, Min Jun Kim, Gyu Hyun Go and Seung Rae Lee

430 **Architectural Requirements for Improving Social Interactions in Subway Stations: An Evidence Based Design Approach**
Hessam Ghamari, Cherif Amor and Karim Mardomi

438 **Human Factors in the Analysis of the "Tram-Car Drivers" at Intersections**
Fatiha Moutchou, Abdelghani Cherkaoui and El Miloudi El Koursi

446 **A Comparison of Different Approaches in Numerical Modeling of Pavement Granular Material**
Behzad Ghadimi, Hamid Nikraz and Colin Leek

456 **Investigation in Mathematical Models of Chloride Diffusion Coefficient in Concrete Exposed to Marine Environment**
Farhad Nabavi, Shami Nejadi and Bijan Samali

464 **Statistical Significance of Reduction in Load Bearing Properties of Crude Oil Contaminated Soil in Kwale, Niger Delta**
Iloeje Amechi Francis and Okoye Victor

470 **Durability of Stress Ribbon Bridge Checked during Loading Test**
Bogusław Markocki and Marek Salamak

Construction Management

477 **Application of the Principles of Lean Thinking in the Post Construction Department**
Daniel Cupertino, Tatiana G. do Amaral, Sammea A. Vilarinho and Leonardo Alencar

486 **Sustainable Maintenance of Rural Roads in Slovakia**
Lubomir Pepucha and Lubos Remek

492 **A Comparative Analysis of Owner-Contractor Agreements in the Turkish and US Construction Industry**
Pinar Irlayici Cakmak and Elcin Tas

Historic Architecture

499 **Tourism as an Industry in Heritage Site—A Case Study on World Heritage Site of Fujian Tulou**
Xiaomei Zhao

509 **Causes of Buildings' Abandonment in the Years 1960-1990**
Alfonso Magaz Robain, Enrique Perea Castaño and Raul Rodriguez de Torres

Apr. 2014, Volume 8, No. 4 (Serial No. 77), pp. 389-394
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Transfer of Ultrafine Particles and Air in Multi-storey Buildings

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Abstract: An emerging issue in Denmark is passive smoking in residential buildings where non-smokers are exposed to smoke from their neighbours. There are various ways that smoke is transferred from one flat to another. The air transfer rate between two flats in a multi-storey building depends on its construction, tightness and age. This paper presents results of a study on the transfer of ultrafine particles and tracer gas in an older multi-storey building in Copenhagen. The aim of the study was to quantify the transfer of ultrafine particles and gases from one flat to another flat before and after sealing the floor. A new floor-sealing method was applied to seal the floor between the two flats. The sealing method was developed by a firm specialising in sealing. Indoor ultrafine particle concentrations and tracer gas were measured continuously in the two flats during the measuring periods. In the unoccupied flat, the gas source was N_2O and the particle source was burning cigarettes. Reduction of the concentration of ultrafine particles and tracer gas by sealing the floor with polyethylene and joint filler made of bitumen was studied. It was evaluated how the sealing performed with regard to decreasing the amount of ultrafine particles and a tracer gas transferred between two flats separated by a floor. When the floor between the flats was not sealed, the results showed that about 4% of the ultrafine particles and 14% of the tracer gas were transferred. After sealing, the amount transferred was reduced to 1.6% and 5%, respectively.

Key words: Particles, air pollution, ventilation, full-scale experiments.

1. Introduction

In multi-storey buildings, it may occur that residents are exposed to the polluted air from the surrounding flats. The polluted air is usually associated with odour from activities such as cooking and/or tobacco smoking. Tobacco smoke is harmful and therefore technical solutions need to be developed in order to reduce the transfer rate of UFP (ultrafine particles) in multi-storey buildings.

To what extent air pollution—airborne particles—is transferred from one flat to another depends on the construction of the building, its age, density and ventilation system. An earlier study examined the transfer of UFPs from one flat (source flat) to another (exposed flat) [1]. The study showed that approximately 9% of the particles from tobacco smoke are transferred when the exposed flat is directly above the source flat.

Previous research is studied three technical solutions to reduce the transfer of UFPs in multi-storey buildings [2]. The first study examined the sealing of the floor of the exposed flat. The other study examined the use of a novel air cleaning duct (photochemical air purification) and the third examined a portable AC (air cleaner).

The first technical solution was tested in a flat in a multi-storey building from the 1930s. Cardboard and plastic foil of polyethylene was used for sealing the whole existing wooden floor in the exposed flat. The results of the study showed that after the sealing, the concentration in the exposed flat was independent of the generation of UFPs in the source flat.

The second solution was examined in a laboratory environment. The efficiency of the novel air circulating ductwork was examined by investigating the removal rate of UFPs from a lit cigarette. The test showed that the efficiency of the removal rate went from 30% to 60% after 10 min, i.e., when the cigarette had burned out.

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The third solution with a portable air purifier was investigated in a flat of 110 m^2. In this case, the efficiency of an air cleaner was studied in relation to the reduction UFPs from tobacco smoke. By using an air purifier with a CADR (clean air delivery rate) of 240 m^3/h the effectiveness of the air purifier ranged between 65% and 75% depending on its location in the flat in relation to the location of the UFP generating source [3].

Older multi-storey buildings often have leaks that UFPs can pass through. There are leaks from piping in the floor and along the walls. Studies show that UFPs are not only transferred through the floor but also along the stairwell [1].

This study investigates a new sealing method. It shows that application of the sealing method reduces the transfer of air and particles between two flats.

2. Methods

The study was carried out in a block of flats built in 1881. The exposed flat was directly which is above the source flat. The experiments were performed in January and February 2012. During measurements, no indoor activities took place—i.e., cooking, cleaning or other activities that could generate particles.

Fig. 1 shows the floor plans of the two flats. The exposed flat and the source flat are laid out the same way. The volume of the flat is approximately 120 m^3. The flats consisted of a living room facing a busy road, a room and a kitchen facing a courtyard, a combined toilet/bath and an entrance centrally located in the flat. The floor of the flats was a varnished wooden floor in the living room, the room and the entrance. The kitchen had vinyl flooring and the bathroom floor was covered with tiles. The kitchen had cabinets along the inner walls and a sink under the window. The living room and the room had skirting boards along the walls and the ceiling had mouldings. A rosette with a power outlet was positioned in the middle of the ceiling of the living room and the room. A radiator with a heat pipe leading through the floor was placed under each

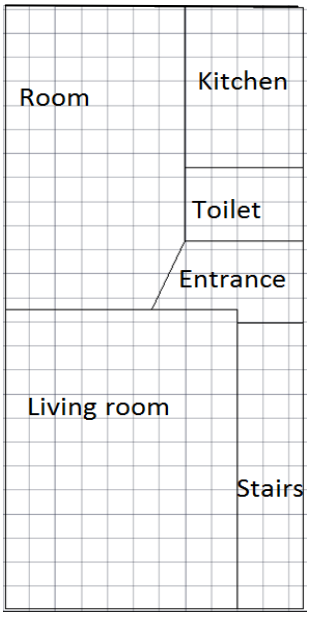

Fig. 1 Floor plan of the flats.

window in the living room and the room. There was ventilation in the toilet/bathroom. All the windows had fresh air vents.

With the purpose of creating an overpressure in the source flat compared with the exposed flat, a higher temperature was established in the source flat. This was ensured by maintaining the temperature of the source flat at 5 ^oC above the temperature in the exposed flat. During the examination, the temperature in the exposed flat was approximately 20 ^oC and in the source flat it was approximately 25 ^oC.

The UFP generating source consisted of four lit cigarettes that were placed in the lower flat, two in the living room and two in the room. All cigarettes were simultaneously extinguished after a period of 10 min. The UFP concentration was measured by means of two particle counters NanoTracer PNT 1000 from Philips and one CPC (condensation particle counter) model 3007 from TSI Incorporated. The particle counters measured concurrently. The two NanoTracer PNT 1000 were placed in each of the flats and the CPC 3007 was placed outside.

Besides particles, the air change rate and the air transfer rate between the flats were measured by means of two Multi-Gas monitors, type 1302 from Brüel and

Kjær, placed in each of the flats. Temperature and humidity were measured every 5 min with TinyTag data loggers type TGU-4500 from Gemini. During UFP generation complete mixing was achieved by means of small fans in the room. A top window in the façade the busy road was opened approximately 2 cm in the source flat. All fresh air vents were also opened and the exhaust in the toilet/bath was closed. In the exposed flat, all windows, exterior doors and fresh air vents were closed. In the toilet, the exhaust was open.

The first part of the experiment was performed without sealing the floor in the exposed flat. The second part of the experiment was carried out after the floor had been sealed in the exposed flat.

When the measurements were started, the UFP concentration in the flat was almost constant with a background concentration of about 10,000 UFP per cm^3 in the source flat. In the exposed flat, the background concentration was 4,000 particles per cm^3. Four cigarettes were lit in the source flat, two in the room and two in the living room. The cigarettes were extinguished just before they burned out. The measurements continued until the UFP concentration in the two flats almost reached the initial concentration.

Before the last measurements, the floor in the exposed flat was sealed. The sealing method was developed by a firm specialising in sealing. The company chose to seal the floor by fitting a vapour barrier, Icopal Blackline, made of polyethylene. The vapour barrier was made by overlapping pieces bonded together with joint filler made of bitumen. The vapour barrier was placed along the floor and up the walls, where it was sealed along the skirting boards with a building sealant approved for indoor use. At the heating pipes, the vapour barrier was sealed with joint filler made of bitumen. It was not part of in this study to determine whether the products used contributed to the concentration of particles in the exposed flat.

3. Calculation Methods

The transfer of UFPs and gas was calculated by applying a calculation method Eq. (1) used in previous experiments on second-hand smoke [1].

$$c_{r(t)} = \frac{c_s \dot{V}}{\dot{V} + rV} + \frac{\dot{M}}{\dot{V} + rV} - \frac{\dot{V}}{\dot{V}+rV}\left[c_s + \frac{\dot{M}}{\dot{V}} - \frac{\dot{V}+rV}{\dot{V}} c_{r(0)}\right] e^{-\left[\frac{\dot{V}}{V}+r\right]\tau} \quad (1)$$

where,

$\dot{V}$ is the airflow rate (m^3/h);

$\dot{M}$ is the UFP transfer from flat 1 to flat 2 ((particles/m^3)·(m^3/h));

c_s is the UFP concentration in supply air (particles/m^3);

c_r is the UFP concentration of air in the flat (particles/m^3);

V is the volume of the flat (m^3);

R is the UFP removal rate (h^{-1}).

The air change rate in the two flats was calculated by applying the decay method and the air change rate was determined by dosing a tracer gas in the flat 2.

The tracer gas was distributed in a way that total mixing was guaranteed. After dosing of the tracer gas, the decay rate of the tracer gas was measured over time. The air change rate was calculated by the decay curve.

$$C(t) = C_0 e^{-nt} \quad (2)$$

where,

C_0 is the initial concentration in ppm;

$C(t)$ is the concentration in ppm after t;

t is the time in hours;

n is the air change rate in h^{-1}.

4. Results

4.1 Before Sealing

Four cigarettes were lit in the source flat, two in the living room and two in the room. The cigarettes were lit at the same time and extinguished just before they burned out. Fig. 2 shows them easured UFP concentrations in the source flat and the exposed flat. Before UFP generation, the background concentration of UFPs in the source flat was approximately 10,000 UFP/cm^3 and in the exposed flat approximately 4,000 UFP/cm^3. The reason for the high background

concentration in the source flat was that the resident in the source flat was a smoker and smoked indoors. The UFPs from the tobacco smoke deposited on surfaces such as furniture, walls and curtains [4]. The maximum UFP concentration in the source flat was measured at approximately 650,000 UFP/cm^3. In the exposed flat, the maximum UFP concentration was measured at approximately 11,000 UFP/cm^3. Fig. 2 shows that the maximum concentration in the exposed flat took place 30 min. after the cigarettes were extinguished.

The transfer rate of UFPs from the source flat to the exposed flat was found to be approximately 4%.

The air change rate in the source flat was calculated at 1.25 $h^{-1}$and at 0.18 h^{-1} in the exposed flat.

The transfer rate of tracer gas was calculated at approximately 14% , as is shown in Fig. 3.

4.2 After Sealing

After sealing, the transfer rate of UFPs was reduced from 4% to 1.6% and the transfer rate of tracer gas was reduced from 14% to 5%. The results showed that sealing more than halves the transfer of UFPs and tracer gas.

After the cigarettes were lit in the source flat, the concentration in the exposed flat was at the highest level after approximately 30 min, as is shown in Fig. 4.

The initial UFP concentration in the exposed flat was higher at the beginning of the experiment, than when the cigarettes in the source flat were ignited. This was because the residents were at home right up to the start of the study.

After sealing the floor in the exposed flat, the air change rate in the source flat was calculatedat1.46 h^{-1}. In the exposed flat, the air change rate was calculated at 0.52 h^{-1}. The air change rate before sealing the floor was 1.25 h^{-1} and 0.18 h^{-1}, respectively. The difference in the air change rate may be due to the fact that when the floor was sealed, a hole was made in the outer wall for a balcony. During the experiment the hole was sealed with a mattress but no insulation. As the flat was less insulated the transfer might have influenced the air change rate resulting in a different air change rate. The wind speed for outdoor air was on average 6 m/s and 3 m/s in both cases [5]. This indicated that the wind speed cannot explain the increase in the air change rate.

After sealing the floor of the exposed flat, the transfer rate of tracer gas from the source flat was calculated at 5%, as is shown in Fig. 5. Before sealing the floor the transfer rate was 14%.

5. Discussions

There are more than 30 different VOCs (volatile compounds) in tobacco smoke and highly volatile compounds deposit on surfaces and in the indoor environment where the pollution occurs [6]. Tobacco smoking generates more than 4,000 different chemical compounds during combustion [1]. During combustion, both gases and particles are emitted. For most people, odour limits whether or not tobacco smoke is acceptable in the indoor environment. The concentration of the particles depends on their volatility [7]. The concentration of particles also depends on temperature (increasing degassing with increasing temperature), humidity changes and ventilation [4]. Some of the particles deposit on other materials, in particular furry textiles. If for example, the air change rate is low during a weekend the emitting products deposit in the indoor environment. They do not disappear just because the space is ventilated.

5.1 Gas

To investigate the transfer of gases, a tracer gas of N_2O was used. Since a lit cigarette emits thousands of different gases consisting of several molecules, it is not possible to measure the mall. Instead a measurable nitrogen tracer gas was used.

The investigation showed that the transfer of tracer gas was reduced from14% to 5% after sealing the floor in the exposed flat.

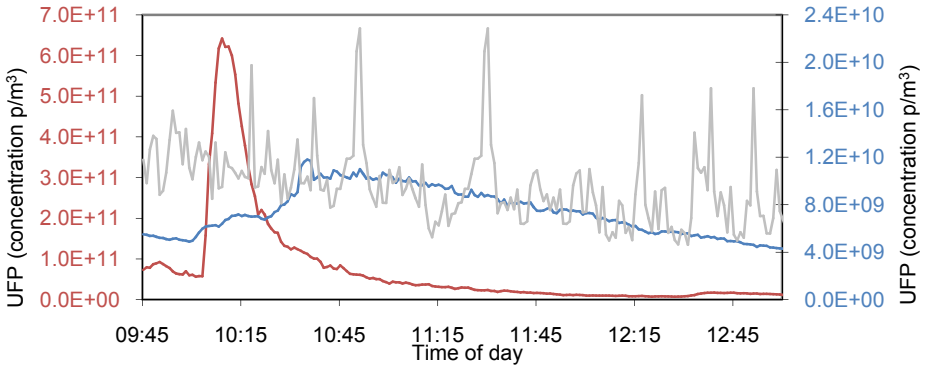

Fig. 2 UFP concentration in the flats (red: the source flat, blue: the exposed flat, grey: outdoor).

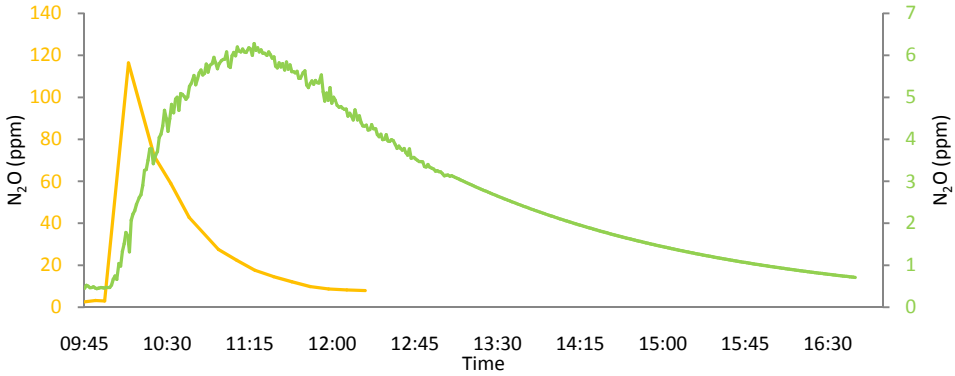

Fig. 3 Tracer-gas concentration in the two flats (yellow: the exposed flat, green: the source flat).

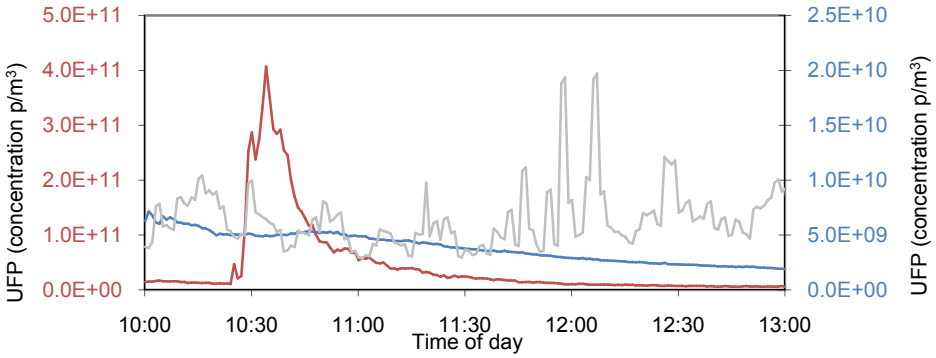

Fig. 4 UFP concentration in the flats (red: the source flat, blue: the exposed flat, grey: outdoors).

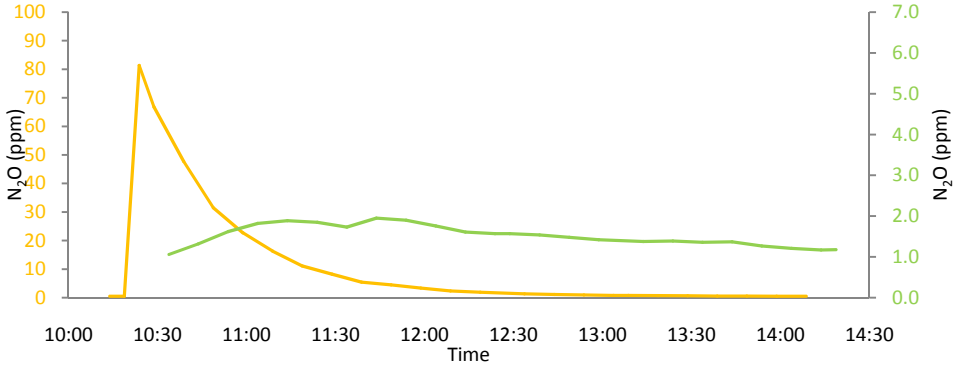

Fig. 5 Tracer-gas concentration in the two flats (yellow: source flat, green: exposed flat).

Because the dosed tracer gas was N_2O, the measurements were certain to be only of the tracer gas. However, it was uncertain whether it was transferred through the floor or through other leaks in the structure.

Since only a single gas of a specific chemical compound was measured, it is difficult to say how much the gasses from tobacco smoke can be reduced, when compared with the large amount of different gasses in tobacco smoke.

5.2 Ultrafine Particles

The transfer of UFPs was examined by measuring the concentration before and after the floor was sealed. The transfer rate of UFPs was reduced from 4% to 1.6% after sealing the floor of the exposed flat.

This study showed that the transfer rate of UFPs was lower than the transfer rate of tracer gas. During the experiments without a sealed floor, 14% of the tracer gas was transferred while only 4% of the UFPs were transferred. This could be due to the fact that the UFPs deposition surfaces such as furniture and walls, and in cracks in the flat. Other factors, such as coagulation, sedimentation, condensation of water vapour on small particles, etc., also play a role.

6. Conclusions and Future Work

The applied sealing method resulted in a reduction of UFPs and tracer gas from the source flat to the exposed flat by more than half.

After the floor was sealed in the exposed flat, the transfer of UFPs was reduced from 4% to 1.6%. This was less than half of what was transferred before the floor was sealed. Transfer of gases was reduced from a transfer rate of 14% to 5%.

The investigation was performed in an older multi-storey building from the late 1800s. In Copenhagen, there are great many buildings of this kind. To verify the study, it is necessary to test several different types of multi-storey buildings.

New sealing materials are being developed and there is a need to test them in various types of buildings.

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Teaching Sustainability in Design without Greenwashing

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Abstract: Teaching design incorporating a sense of sustainability to architecture students is a challenge today, primarily because of the trend to label every design as sustainable or green even though it is no different from a more traditional one. The result is a "green-washed" education in architecture. To address this issue, this paper describes a teaching methodology of architectural design with a special focus on sustainability implemented in the Graduate School of Architecture in Clemson. This method includes an analysis of the location, the climate conditions, the materials needed and the construction process. Knowing that sustainable design is generally perceived as being expensive, there is a special focus on simplicity and affordability. Rather than relying on expensive technical solutions, students are encouraged to design for the given environment and apply passive strategies. In the approach discussed in this paper, the design process is a number of logical scientific decisions rather than an intuitive draft. The goal of this pedagogy is to raise awareness about how to handle global resources carefully and to show the importance of the later performance of the project as a key to design. The teaching strategy is described here along with the successful participation by our graduate students in a number of refereed competitions.

Key words: Sustainability, design, teaching, passive design strategies, energy efficiency, affordability.

1. Introduction

All basic needs for human survival come from the natural environment—light, water, air, food, minerals and materials. Sustainability is a frame of mind in which we see ourselves as part of this environment, not as consumers of it, and, therefore, conservers of these resources not only for ourselves but also for future generations. The current anthropocentric view of the planet is one in which we have the right to exploit "our" land as we see fit, regardless of the larger consequences to other organisms or the complex cycles regulating the environment. In contrast, the sustainable concept is one in which we see ourselves as part of a larger whole, one without which we cannot survive. Sustainability is an approach which emphasizes stewardship, not ownership, which makes us aware of and responsible for every action we take, and which attempts to create and maintain the conditions under which humans and nature can coexist in productive harmony.

Applied to architecture, sustainability is the managing of resources in order for a building to operate efficiently and function based on an environmentally sensible design. The primary strategies for achieving this goal is through the use of local renewable, durable materials and passive and active systems. Local and renewable materials reduce energy use in transportation and manufacturing, and the durability of these materials extends their life spans while at the same time reducing the maintenance required. Passive systems reduce the amount of energy required by using energy-neutral architectural devices and systems, and active systems take this a step farther by resulting in negative energy use, bringing the energy performance below zero mark.

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2. Integrated Design or Greenwashing?

Integrated design, a comprehensive method emphasizing the development of a holistic design, evolved, in part, because of the current focus on sustainability. In contrast, conventional building design usually considers the spatial design first and then the technical aspects such as structure, mechanical systems and energy reducing strategies. This design method does not involve all of the necessary technical fields in the planning and design process, and therefore does not take into account their needs. As a result, in some instances, incompatible elements of the design are not discovered until late in the process when it is "against the concept" to make changes. Integrated design, on the other hand, requires multidisciplinary thinking as it involves a "whole building design" approach. It views a building as an interdependent system as opposed to an accumulation of separate components (site, structure, systems and use). The goal of considering all the systems together is to ensure that they work in harmony rather than against one another. This approach appeals to architects since their discipline requires a broad knowledge of related disciplines such as structures and mechanical systems, meaning that the product of architectural design is a result of logical and scientific decisions rather than a piece of spatial art.

However, rather than incorporating integrated design into sustainable architecture, what resulted was greenwashing, the opposite of both concepts. The term greenwashing, coined by New York environmentalist Jay Westerveltin in 1986, is generally used when significantly more money or time is spent advertising being green, i.e., operating in consideration for the environment, rather than spending resources on environmentally sound practices. This practice often changes the name or label of a product or a piece of a design to evoke the natural environment or nature, for example putting a green roof on a home at the very end of the design process.

3. Case Study/Dow Solar Design to Zero Competition 2011

3.1 Background

To address some of the world's most pressing environmental issues, Dow Chemical Company sponsored a competition in 2011 on innovation and sustainable solutions. Contestants were asked to develop and propose novel ideas for achieving affordable, high-performing, energy-efficient housing solutions on a global scale. This competition was open to all undergraduate or graduate students worldwide studying design, interior design, sustainable design and other relevant subjects. It was envisioned as a global brainstorming exercise in which competitors would cooperate in an ongoing dialogue and assessment of ideas. The competition was peer-reviewed in three elections: (1) schematic design; (2) design development; (3) final design.

Clemson University participated with seven graduate student teams advised by assistant professor Ulrike Heine (design + sustainability) aided by associate professor Dan Harding (community design + built) and Bernhard Sill (design + structures). Of these seven, six teams were named finalists and five earned awards, including a first and a second prize. The submittal was a website.

3.2 Research

As a first step, students were requested to chose a site for their project and to research the local conditions in detail, including the zoning of the site, the local transportation and the surrounding architecture in addition to the local building materials and construction methods. A special focus was to be local historic architecture from the time before the invention of air conditioning.

The second stage of the research focused on the specific climate of the location, the maximum and minimum temperatures for the year, the seasons and the day, the wind speed and directions, the humidity levels and the amount of precipitation throughout the

year. The research also included the evaluation of the initial suggestions for materials, the orientation of the building, the active strategies for energy conservation and the passive strategies, like orientation, for improved general performance.

The third component of the research was conducted on the specific building typology of the design task—in this case residential buildings—the definition, the internal organization, the optimized measurements according to Ernst Neufert, and the codes required. Case studies from all around the world were analyzed for their cultural differences and to question the students' personal experiences.

The following graphics are the exemplary submittance of one of the award winning projects.

The project is located in downtown Greenville, South Carolina (Figs. 1a and 1b), the second largest city in the state with a metropolitan area population of 636,986. The site is in walking proximity to important cultural centers, parks, restaurants, schools, amenities and businesses. Site conditions include a slope of approximately 13.2% along the east-west axis, existing hardwood trees, a clinic building to the north, residences to the east and south, and a public park to the west.

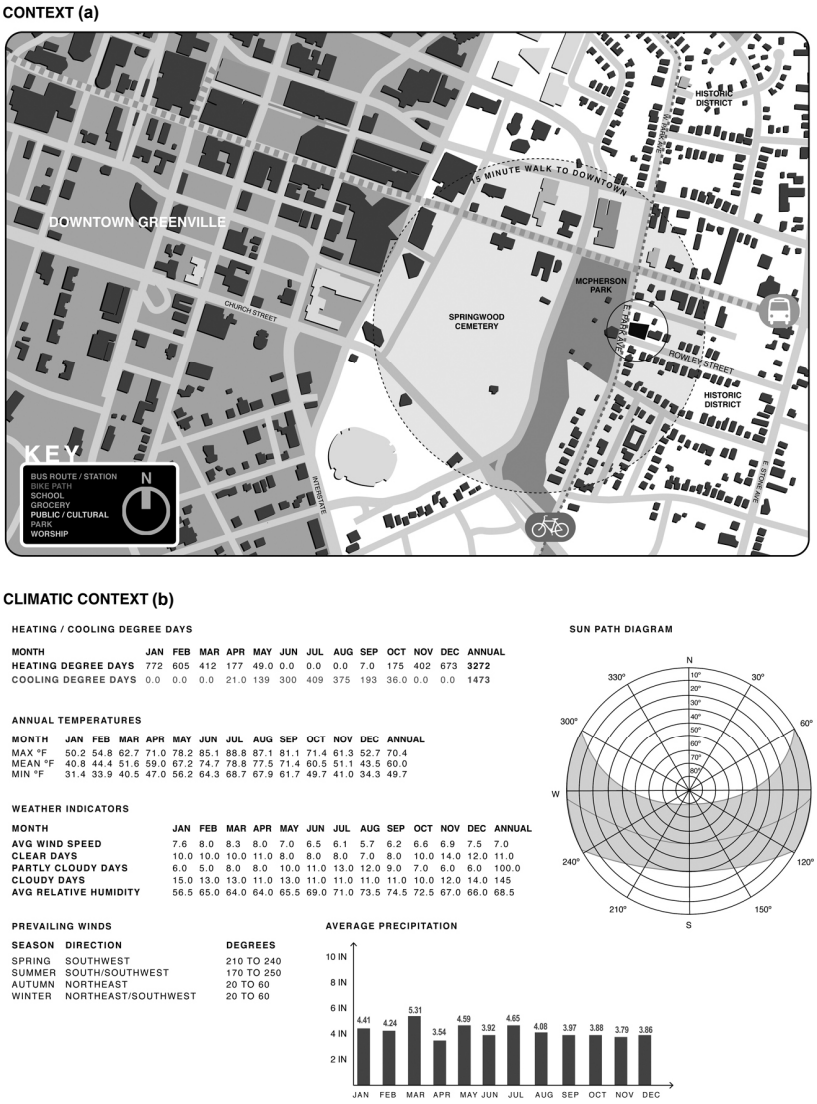

Fig. 1 Design to zero competition [1]: (a) site context; (b) climate analysis.

3.3 Programming

One task of the competition was the definition of a program of a 2, 4 and 6 person household. According to census data, the size of American housing dramatically increased from 1950 until 2008, when it decreased by 1.6% as a reaction to increasing energy costs. Since then a minimal, but continuous decrease in the size of the average residential home has been observed.

Challenged with the task of creating a vision for the home of the future, the students were requested to recalculate the spatial needs of a family, keeping in mind that every cubic feet of space was to be supplied with energy provided by their own energy-gaining devices.

After an analysis of which spaces are occupied during the day and night and how they can be optimized, the teams reduced the average house size by 25%-40%, combining the social spaces like the living, kitchen and dining areas to create one spacious area while reducing the bedrooms and bathrooms to functional units (Table 1).

3.4 Design Concept

All of these design concepts were then placed in urban and spatially defined conditions, with a special emphasis placed on implementing the design in response to given contexts and building lines. As a basic strategy, it is expected that environmentally friendly buildings need to be linked to sustainable urban strategies in order to avoid further spread of surburbia with its negative impacts of commuting, unnecessary land consumption and the degrading of the population [3]. The background research on the local conditions and climates shaped the buildings in terms of their geometry, orientation and size (Fig. 1a).

Table 1 U.S. Census Bureau, median and average square feet of floor area in new one family houses sold by location, 2008 [2].

Year	Avrage ft^2 / Household	Increasing size in %
1950	983	100%
1980	170	172%
1985	170	179%
1990	250	208%
1995	2,050	208%
2000	2,265	230%
2005	2,414	245%
2006	2,456	249%
2007	2,479	252%
2008	2,438	248%

4. Passive Design Strategies

Their research provided the students with tools and information to shape their concepts through passive strategies, the idea being to achieve improved performance before thinking about energy gaining strategies. Simulations on design builder showed that the performance of a design incorporating such passive strategies is already 30% more efficient than a standard design. The following strategies were implemented in the students' designs, although not all of them were brought into every concept.

4.1 Compactness (Building Form and Building Proportions)

The compactness of a building, which measures the surface area (S) per volume unit (V) (compactness = S/V), is related to the heat exchange between the building and the ambient environment and, therefore, according to the thermo-physical characteristics of its materials defines the ability to store and release heat. The ratio of volume to surface is an indication of the rate at which a building heats up during the day and cools down during the night. In any project, the urban design is defined by the parameters of distance between buildings (density), orientation, access, parking and open spaces, all of which influence later energy use.

The building form and its compactness are relevant to the amount of heat loss, which is proportional to the insulating quality and to the heat transmitting surface. The most compact shape for a freestanding house is a cube. The design of an individual house should be

considered with regard to compactness, natural lighting and solar heat gain.

The project redefines the living unit by decreasing the size, cost and energy footprint without diminishing design or sacrificing detail. The building maintains a level of simplicity through form, particularly in plan, but affords spatial complexity through experience, particularly in section, where forms interlock and layer to generate zones, increase ventilation and provide overhangs and adjacencies. The design incorporates planned ambiguity that blurs the boundary between interior and exterior spaces (Fig. 2), creates moments of pause and framed views, and plays with light for both aesthetic and environmental purposes. The units are all tied together by the central underground shared mechanical room, accessible through the parking area, where water and energy are stored and distributed.

4.2 Orientation

The orientation of a building must be considered in relation to the sun and prevailing winds. Unfortunately, in most situations they are not compatible and, as a result, compromises must be made. The solar orientation determines the intensity of the solar radiation, therefore, the following rules need to be considered: The greatest intensity of solar radiation occurs on horizontal surfaces; The greatest intensity of solar radiation on vertical surfaces is on the eastern (morning) and western (afternoon) façades; The southeastern surface is subjected to less radiation during the hot season (high temperature) and more during cold seasons (low temperatures); The radiation increases in northerly latitudes. To determine the equilibrium between the welcome solar gain in winter and protect against the undesired solar gain in summer,

Fig. 2 Design to zero competition, spatial concept [1].

shading devices, operable and permanently installed, need to be implemented into the design. The wind orientation should be considered to maximize the natural ventilation. The greatest pressure on the windward side of a building is obtained when it is perpendicular to the direction of the wind, but even openings at a 45-degree angle to the prevailing wind direction increases the air velocity and improves the natural ventilation within the building [4]. Each building has to be studied holistically, taking into account all aspects of the bioclimatic design.

While working on their projects, the students were encouraged to simulate their designs in such programs as Ecotect or Sketchup to determine the optimal orientation and exposure to the sun.

4.3 Passive Ventilation

Ventilation should allow fresh air from the outside to flow through the building to facilitate, for example, evaporative cooling of the air, the occupants and the structures. Normally the openings for air movement correspond poorly with the ones for natural lighting, therefore, they should be treated separately. In general, there are two kinds of natural ventilation:

- through wind-generated pressure differences (i.e. different sizes of openings);
- through temperature-generated pressure, differences (natural lifting forces).

If the specific climate of the project provides a sufficient difference in temperature between day and night, night cooling should be considered as an efficient method of passive cooling. In this situation, the building should be closed during the day to avoid an overheating of the spaces and be opened during the night [5].

The complex is oriented along the east-west axis to maximize solar gain and take advantage of existing wind patterns (Fig. 3).

4.4 Passive Solar Design

Passive solar design refers to the use of the sun's energy for the heating and cooling of inhabited spaces. Using this approach, the building itself, or some element of it, takes advantage of the natural energy characteristics in the materials and the air created by exposure to the sun. Passive systems are simple, have few moving parts, require no mechanical systems and involve minimal maintenance.

Operable windows, thermal mass and thermal chimneys are common elements found in passive design. Operable windows, which are windows that can be opened, should be oriented properly and their size optimized. Thermal mass, which refers to materials such as masonry and water that can store heat energy for an extended time, prevents rapid temperature fluctuations. Thermal chimneys create or reinforce the effect of hot air rising to induce air movement for cooling purposes.

4.5 Passive Cooling

Cooling is linked to the concepts of ventilation. If the temperature inside is higher than outside, the heat

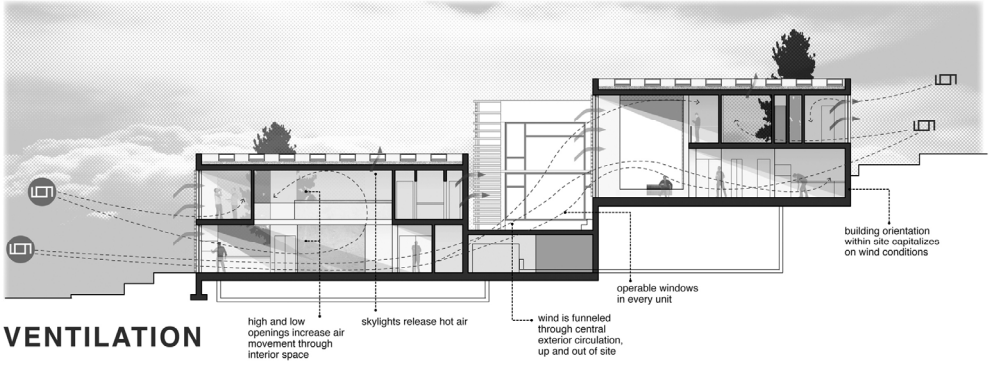

Fig. 3 Design to zero competition, ventilation concept [1].

can be removed through natural or mechanical ventilation. Cross ventilation forced by openings on two sides of the space optimizes natural heat extraction. Convective ventilation, usually realized in spaces with high ceilings, takes advantage of the natural lifting forces and replaces the rising warm air with fresh air. The higher the space, the higher the air change rate. Heavy, massive elements can provide thermal capacity for the absorption of internal heating loads and the temperature fluctuation in a space. This approach, referred to as Building Component Activation, takes advantage of this and warms or cools such solid building components as walls or ceilings through active (water) or passive (ventilation) measures.

4.6 Natural Lighting

The goal of planning the lighting is to achieve maximum daylight autonomy through the optimization of the building. The openings need to be designed to provide an optimal amount of light in the house while at the same time being adjustable to create an appropriate shading device when needed. At times, natural light is not feasible or even undesirable, in these situations, an adequate source of artificial light needs to be provided, one that fits the needs but uses as little energy as possible. Numerous computer programs can be used to simulate the light situation in a building. Topics like color distortion, freedom of glare and good contrast should be considered [5, 6].

The redefined unit maximizes natural daylight while also affording the users a high level of control over their environment. Each space within each unit is penetrated by natural light during the day. Interior spaces expand their minimal footprint by opening onto exterior living spaces and taking advantage of the moderate climate (Fig. 4).

5. Active Design Strategies

The following active design strategies were brought to the students' attention in a separate seminar covering building technology and technical resolution. All students were required to take this class in addition to the studio. Every strategy was analyzed based on their applicability to the specific climate zone and local conditions.

5.1 Photovoltaic

Photovoltaic panels produce electrical power on site by converting solar radiation into direct current electricity, either as a stand-alone or a grid-connected system [5, 7]. The students were challenged to orient and tilt them optimally and integrate them into their designs. They were requested to estimate and calculate the energy needs of the households and size the systems accordingly (Fig. 5).

The optimal way to save embedded energy and money is to make buildings last longer. The redefined unit uses durable, local, sustainable and beautiful materials. Smart active systems are installed, and are

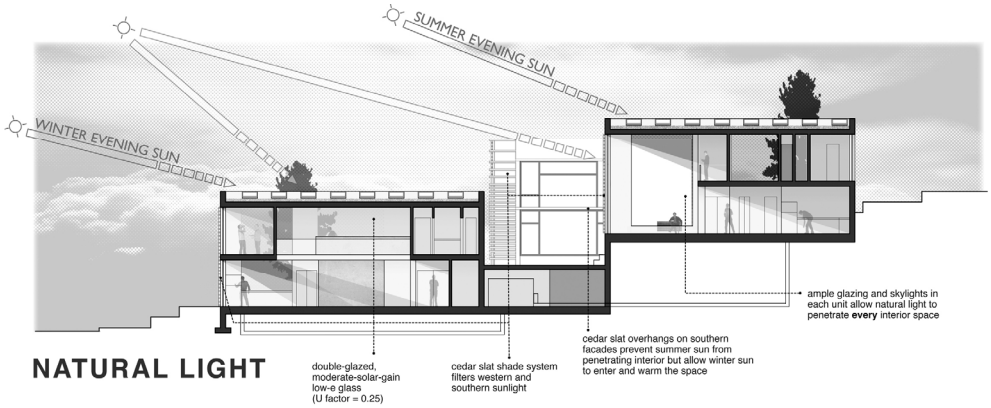

Fig. 4 Design to zero competition, light concept [1].

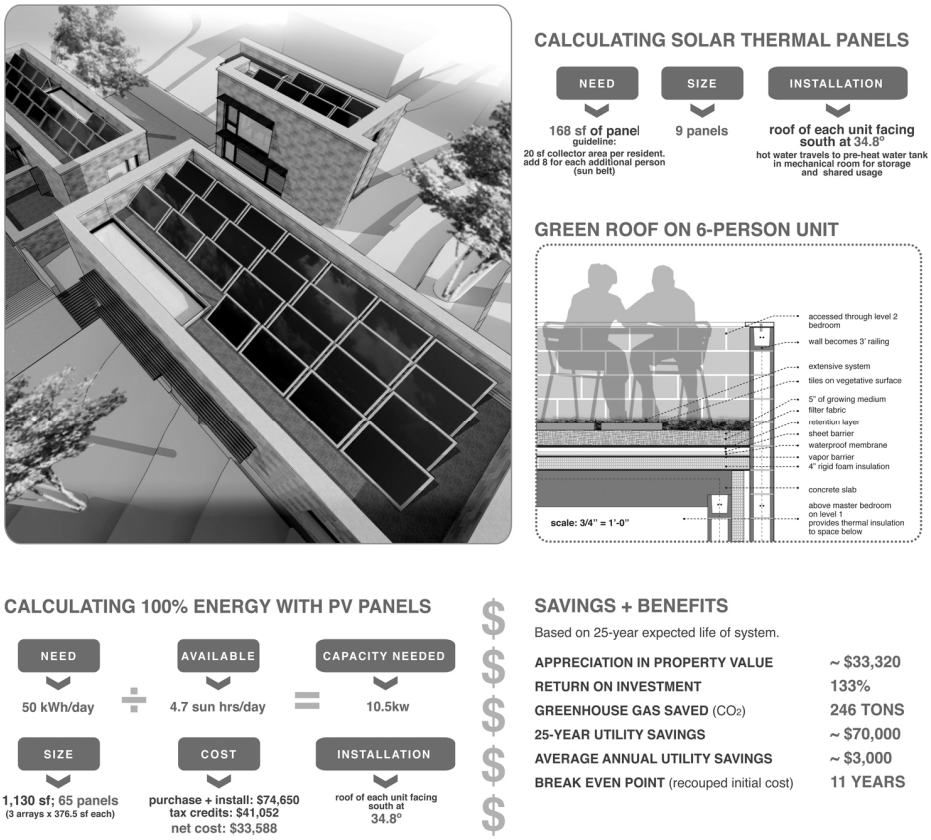

Fig. 5 Design to zero competition, roof system—energy and hot water [1].

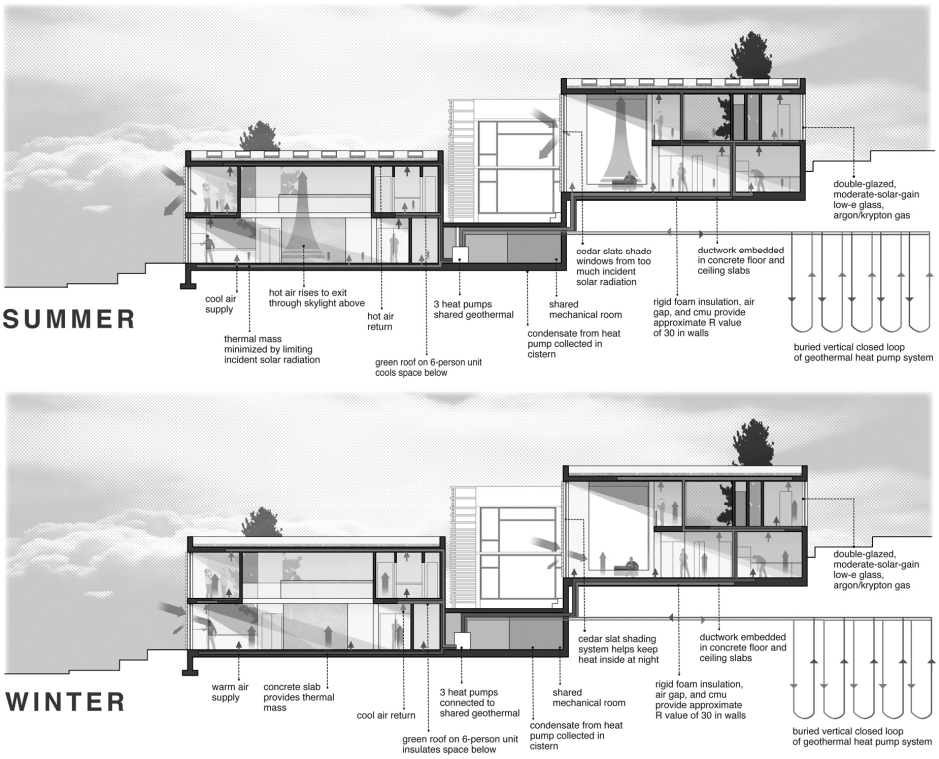

Fig. 6 Design to zero competition, heating and cooling concept [1].

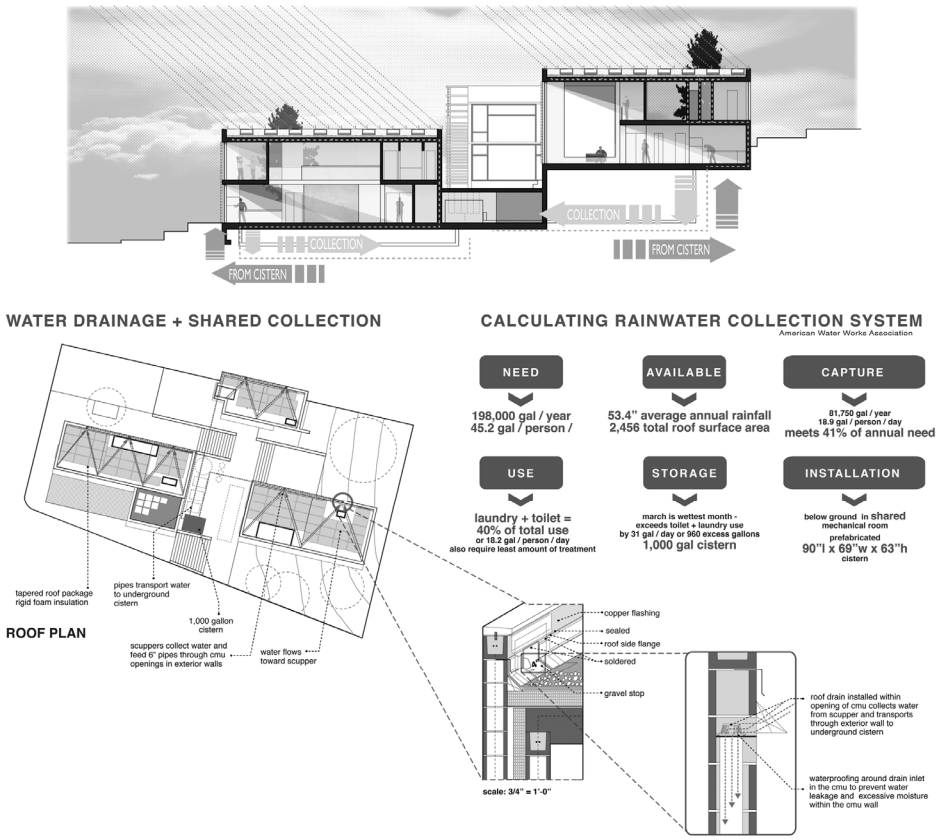

Fig. 7 Design to zero competition, rainwater collection [1].

powered 100% with energy harvested through the photovoltaic system.

5.2 Geothermal/Ground Heat Pump

The ground heat pump is a central heating or cooling system that pumps heat through or from the ground. It uses the earth as a heat source in the winter or a heat sink in the summer. Depending on their sites, students were challenged to decide on an open versus a closed loop or a horizontal versus a vertical loop and air or water delivery. The site had to be analyzed in terms of its annual average ground temperature and its size for the placement of the system [5].

The optimal way to save embedded energy and money is to make buildings last longer. Through passive heating and cooling systems, day lighting, and natural ventilation, energy needs are low (Fig. 6).

5.3 Rain Water Harvesting

Rainwater catchment systems collect and store rainwater for reuse for potable uses, irrigation, laundry and passive cooling [5].

Rainwater is collected and provides a large percentage of the units' water needs. A solar thermal hot water system uses solar radiation to heat the water.

Rainwater harvesting systems, which can be simply constructed from inexpensive local materials, are potentially successful in most habitable locations. The students in the studio were challenged to coordinate their sites, roof planes and materials and define a storage location. Calculations determining the amount of water harvested throughout the year were requested (Fig. 7).

6. Conclusions

It is the author's strong belief that teaching integrated design is the key to sustainable design education. Rather than allowing the design process to be subdivided into concept, design process and technologies, architectural projects should be

developed holistically and be implemented for specific climatic and urban conditions. Fundamental research of the context is the foundation for a scientifically grounded and, therefore, sustainable project. The students participating in this project responded very positively to the content of the studio and their new design tools, which were incorporated in their subsequent projects, continuing their reconsideration and evaluation of their existing design tools, living patterns and values.

Their overwhelming success in the international competition, which included 131 submissions from 19 countries, earning 5 of the 11 prizes suggests that this approach is the best one for teaching the next generation of architects. Co-teaching by faculty with different areas of expertise was also a good experience for the students as they prepare to become practicing architects.

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Fuel Poverty and Comfort in Modern Residential Apartments in Developing Countries: A Case from Jordan

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Abstract: Energy is one of the most important resources in the economy of developing countries. Jordan depends mainly on imported oil and gas at international prices. This creates a heavy burden upon Jordanian national economy, which is reflected in the same time on other sectors of the Jordanian society. The ever increasing fuel prices make it very necessary to look for new renewable energy resources. Jordan as a developing country with its fast growing urban development and construction projects will be studied. It is worthy to study the dynamic relationship between end user, fuel and comfort in the residential sector. Energy is a chronic problem in Jordan, due to lack of non renewable energy resources, the end consumer is influenced by this fact, in achieving his basic energy needs. This study tries to shed light on the fuel poverty line, definitions and parameters of fuel poverty. And to study what has been done in this regard on both international and local level. No studies have been identified in Jordan which, explore the problem of fuel poverty, especially after the vast and recent increase in fuel prices internationally and locally. This study will follow theoretical and field survey to understand the relationship between comfort, energy and building fabric. Method will depend mainly on field survey and statistical data, and necessary measurements, questionnaires will be adopted when necessary to explore comfort levels related to fuel consumption. Summary and recommendations will be concerned with how thermal comfort could be achieved within the ranges of fuel accessibility, building fabric, minimum pollution and cost.

Key words: Fuel poverty, household, residential sector, thermal comfort, primary energy, Jordan.

1. Introduction

Through the total life cycle of buildings, energy is needed for construction, operation and demolition. And this is almost valid under any climatic variation, this of course will be reflected on total building running costs.

Energy flows for any building which takes different fuel types and patterns, from the very fine type of energy like electricity on one hand, to the very crude form like diesel and kerosene.

Our study here is mainly concerned with the residential sector in Jordan for three reasons: First, a residence is occupied continuously for 24 h, and this requires maintaining the required level of comfort; Second, this sector is almost the largest sector in the buildings stock in Jordan; The third reason, is the annual income for individuals who make it necessary to explore energy poverty in this sector, as an introduction to understand, evaluate and measure fuel poverty in this sector.

In Jordan, the number of home owners pays more money for maintaining the required comfort level in their homes; this is due to the successive increase in fuel prices, keeping in mind that a very slow increase in their salaries rarely happens. This in turn raises questions about quantifying fuel poverty in Jordan.

2. Definition of Fuel Poverty

Fuel poverty has been firstly introduced and identified since four decades, its social impact due to the insufficient energy consumption in the domestic

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sector is evident [1].

Fuel poverty is a concept that may take various definitions, a standard qualitative definition first used by Lewis is: “The inability to heat the home adequately because of low household income and energy inefficient housing” [2], this definition was modified by Healy and Clinch [3].

One of these definitions that is used in policy-making is: “A household is in fuel poverty, if in order to maintain a satisfactory heating regime, it would be required to spend more than 10% of its income on all household fuel use including housing benefit or income support for mortgage interest [4]”. Boardman [5] introduced another definition: “It is the inability to obtain adequate energy services for 10% of household income”.

According to Morrison and Shortt [6], several factors affect the concept of fuel poverty, they argued about the preciseness of the definition of fuel poverty, and were called for greater clarity as regarding to income and adequate energy services.

Fuel poverty has certain consequences on health, especially on the elderly, this may lead to a physiological condition in humans known as “cold strain” which may result in cardiovascular and respiratory systems of the elderly, and at worst, chronic strain can result in fatal conditions and mortality [1].

3. Previous Studies and Literature

Studies regarding fuel poverty have been implemented all around world, specifically in Ireland. A project has been made by the British government to alleviate fuel poverty in England which has been conducted, where semi-structured interviews were carried out in a sample of 49 households of those who received energy improvements in five British districts, most householders reported an improved physical health and comfort, little evidence showed lower heating bills in this study [7].

In Scotland, the Scottish executive was concerned with eradicating fuel poverty by 2016, a first step was made by knowing which areas are more likely to contain fuel-poor households, this was done based on local area fuel poverty indicators and on a small area statistics.

Morrison and Shortt [6], proposed an innovative methodology for refinement of the Scottish fuel poverty indicators using GIS software as a framework.

Shortt and Rugkasa [8] reported the findings from an evaluation of fuel poverty program in the Armagh and Dungannon Health Action Zone in northern Ireland. Researchers found that improving energy efficiency in households within the area under investigation, raises the level of thermal comfort and improves health as well, they also concluded that decreasing fuel poverty requires commitment from multiple sectors of society including health professionals and local communities [1, 8, 9].

Another important study was conducted to understand the effect of changing of fuel prices on the ability of household consumers to pay for energy and water this time, this study was done by Tepic and Fankhauser [10] which found that delaying tariff reform by few years makes little difference to affordability constraints, and may not be an effective way to mitigate the social impact of utility reform.

In India, an assessment of the extent of energy poverty and changes in energy distribution patterns are analyzed by applying a novel two-dimensional measure of fuel poverty. Also, they showed the elements of access to different energy types and quantity of energy consumed. It was recommended to apply such new measure to other developing countries [11].

Lenzen et al. [12] analyzed and quantified energy requirements of Sydney households in Australia, where they used input-output analysis with detailed household expenditure data aimed at reaching comprehensive energy use patterns for household consumers, study is applied on fourteen statistical subdivisions of Sydney, data were interpreted using

multivariate regression. Lenzen et al. [12] found strong correlation between energy use and income, household size, age and degree of urbanity. Researchers used structural path analysis to discover the relationship between lifestyles and different energy use characteristics.

In Jordan, few researchers tackled the issue of energy demand and poverty. Jaber and Probert [13] wrote about this issue, they detailed Jordan's pattern of energy use, energy pricing policy, energy types and access, as well as to urban households. And finally they discussed pollutions dissipated from total energy consumption [14].

Researchers in Jordan found no studies to explore the concept of fuel poverty in terms of its economic, social and health measures. All studies may be related to statistical data about energy types available in Jordan's market and some related pollution issues.

4. Measures of Fuel Poverty

Fuel consumption can be measured through different levels of the fuel supply chain, they may be summarized as follows:

- Primary energy which is the energy embodied in natural resources;
- End-use energy which is the energy content of fuel supplied to the consumer at the point of end use, electricity at the electric current meter for example;
- Useful energy which is the energy that has been transformed in the form required for actual use;
- Energy services which is the direct demand by a householder like a hot shower for example.

Different approaches may be followed to measure fuel poverty, they may be stated as shown in Table 1.

Referring to Table 1, Goldemberg estimated basic primary energy needs to be 500 Watt per capita which was based on direct observation of his own energy basic needs, while the Advisory Board on Energy assumed that about 30 Watts of useful energy is needed per capita to meet cooking energy needs, and about 1.5 Watts of useful energy per capita are required to meet space heating needs, and the same amount is needed for lighting needs per capita.

The above mentioned values were calculated on the basis of various assumptions regarding what is considered as the basic minimum required to meet human needs, they count for a total of 33 W of useful energy per capita which is equivalent to almost 250 W of primary energy, which is the half of what Goldemberg has estimated [11].

5. Energy in Jordan and End Consumers

The main problem in Jordan resides in the fact that Jordan has very limited natural energy resources and it depends mainly on imported fuel to satisfy country's energy demands and needs. In past times, Jordan imported fuel from neighboring countries by special offers, which was reflected on alleviating the problem of energy demands in Jordan. Nowadays, there is no

Table 1 Approaches and procedures for measuring fuel poverty.

Measure or approach	Definition and description	Procedure
Economics-based approaches [15]	By defining an energy poverty line or fuel poverty line.	Making calculations to the average level of energy consumption of persons having a level of income or expenditure officially specified by the poverty line or minimum amount needed to meet basic needs.
Engineering-based approaches [16]	Engineering type estimates for determining the direct energy required to satisfy basic needs. And it is estimated to be about 500 W per person per time unit according to Goldemberg estimates.	This is based on a number of assumptions: type of energy consuming equipment, their sizes, efficiencies and intensity of use, the definition of basic needs.
Poverty and access to energy measures	This is achieved by determining access to energy services. As access to more efficient energy sources is related to an improvement in peoples level of well-being. A consumption based measure of energy poverty [17].	

opportunity but to buy fuel from the international market, following the international fuel prices.

Our study is concerned mainly on household energy consumptions, very few studies has been done to study energy demands, consumption and fuel poverty in Jordanian households. There is a need to study measures for fuel poverty in households, because researchers think that day by day the number of household occupants who falls in fuel poverty zone, increases continuously. A need to assess energy quality and energy access is of prime importance as well as it is directly related to the concept of fuel poverty.

As to Jordanian households, ever increasing fuel prices makes it probable that some households lie below the line of those who cannot satisfy their basic energy needs, and may find some difficulties to energy access.

Energy access to Jordanian households is directly related to fuel types used in homes and residences, Table 2 shows end use energy consumption in households in 2000-2005 as well Table 3 shows the development of fuel prices in five years.

Energy consumption for the individual in Jordan increased from 1,015 toe in 2000 to arrive at 1,281 toe in 2005, achieving an annual growth of 4%, and 1,218 kWh to 1,586 kWh in the same period, achieving 4.5% annual growth (Fig. 1) [18].

6. Power Requirements of Energy Services in Households

The average size of Jordanian family is decreasing with time because people are now trying to control new borns because of the high life costs, we may consider that the average size of the Jordanian family is six members household [20].

Table 2 End use energy consumption in households in 2000-2005.

Households	Year					
	2000	2001	2002	2003	2004	2005
End use energy consumption (TOE) × 1,000	881	849	868	945	1,007	1,060
End use electricity consumption in households (GW)	1,981	2,110	2,266	2,471	2,745	2,975

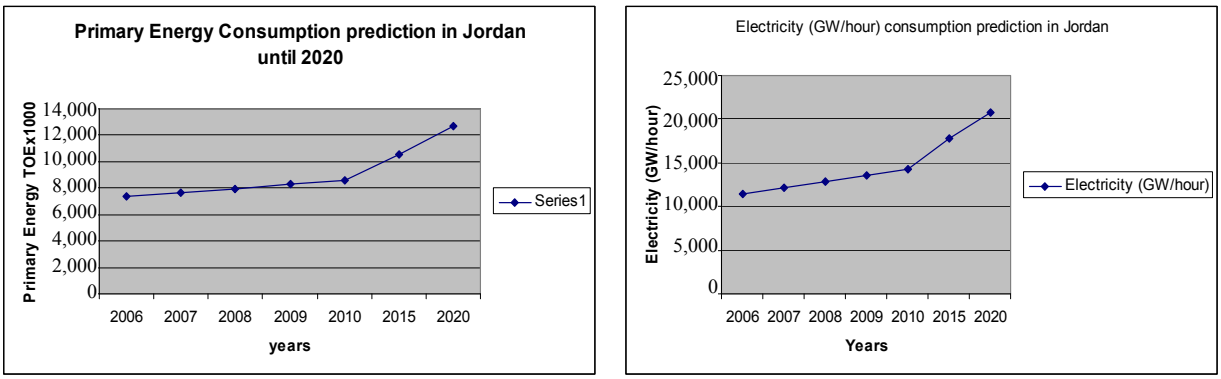

Fig. 1 Primary energy (a) and electricity consumption prediction (b) in Jordan for the coming 12 years [18].

Table 3 Development of fuel prices between 2000-2005 [19].

Fuel type	Unit price	Year					
		2000	2001	2002	2003	2004	2005
LPG (liquefied petroleum gas)	Fils/unit	2,080	2,400	2,500	3,000	3,250	3,750
Kerosene	Fils/L	91	110	120	130	135	220
Solar	Fils/L	106	110	120	130	135	220
Electricity	JD/t	72.5	72.5	77	82	88	180
1 Jordanian Dinar = 1.5 US$. 1 Fils = 0.001 JD							

Energy requirements for the average sized family in Jordan that may ensure acceptable level of life quality has not been estimated until this moment. Calculating basic energy needs for the average household in Jordan, by calculating the end use energy requirements for specific energy services, is an important step, many factors should be determined before starting any estimation of those basic energy needs like, fuel type used, yearly expenditure per capita, household size, household composition for different regions in Jordan.

Household composition is an important factor since young children and elderly people eat less than working adults, therefore, less energy is required for cooking for these members. Meenakashi and Ray [21] performed simultaneous estimation of a system of share equations to determine the scale and composition effects on expenditure shares in India, which showed effective and considerable results in Indian states. Similar work needed to be implemented in Jordan so that basic energy needs could be quantified on a statistical base [11].

7. Analysis of Energy Consumption Patterns in Residential Apartments

Residential apartments were always occupied by a wide variation of occupants who have different monthly incomes. Many of those occupants work in public sector, others are involved in private sector activities.

This work explored the middle income people, an example of these strata is well represented by school teachers working in public schools.

The total number of teachers working in public sector exceeds one hundred thousand teachers, which is considered as one of the largest sectors (Ministry of Education, 2013). It is important to mention here that the range of monthly salary for public school teachers ranges from 280 JD minimum up to 700 JD maximum for a teacher of twenty years' experience.

The field survey was applied on apartments occupied by teachers only, future work may be done to extend this investigation to further house types. Also, a further study may be applied to other different income groups in Jordanian society.

A specific residential zone was chosen for the purposes of this study, picking up only apartments occupied by school teachers. The zone was a neighborhood near Sweileh, a district of Amman city. Related data is shown in Table 1.

The concept about measuring fuel poverty in this study was based upon the monthly net salary for the home owner, according to the definition of fuel poverty previously mentioned in the literature, a 10% of the net salary was calculated, and this value expresses the threshold poverty value for each home owner.

A sample of 25 apartments, were selected for analysis, the net area for each apartment, family size and monthly energy consumption by type were recorded. Fig. 2 shows an example of the architectural layout of one of the studied apartments.

The studied sample shows that all the monthly income for the sample does not achieve the minimum requirements for ensuring minimum energy demands. The 10% of the net monthly income is too small to follow the increasing energy costs.

Therefore, there is an evident proof that some of apartment owners of the total population are under fuel poverty line, whether this conclusion applies for other samples, needs further investigation.

The consequences of this conclusion, imply poor heating, poor cooling, and this is definitely reflected on the comfort inside those apartments, and health problems may arise.

Energy prices are increasing in Jordan on one hand, on the other hand, the net monthly income is increasing very slowly. This fact means that an increasing gap exists between the fuel poverty threshold value and the total energy costs in apartments.

In Fig. 3 as shown, each energy type still below the threshold fuel poverty value, for the three energy

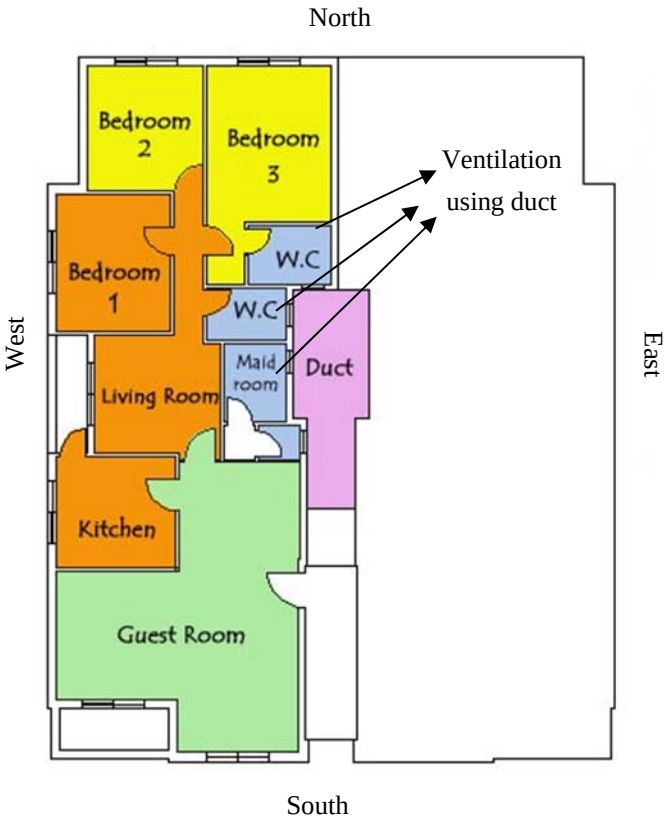

Fig. 2 Example of the architectural layout for one of the studied apartments.

types, electricity, LPG and fuel, but the total summation of them is taken, this new value is always above the threshold fuel poverty value. This indicates that overall energy consumption is still an important problem for home owners. The problem gets more complicated if we know that an expected rise in energy costs is always probable.

While in Fig. 4, it evident that the largest energy consumption in the studied apartments was electricity consumption, other fuel types and the LPG domestic were close to each other, and this is clear since the electricity is needed, and many devices were used. The LPG in apartments is used only for cooking, and in some instances for heating, this explains the reason why they are low in cost values.

8. Conclusions and Recommendations

Crossing through the survey that has been analyzed previously, scientific work has been done exploring this issue on the international level, locally on the national level in Jordan, no work has been implemented to investigate and quantify basic energy needs for the average household.

It is not only important to have detailed statistics about end use energy consumption, but it is more important that we understand how this energy is consumed and the patterns final energy consumption, especially, if we know that the average end use energy percent in household sector was 22.7% of the total energy consumption in Jordan for the years 2000-2005.

Another factor that should be studied and explored in Jordanian household sector which is energy access which means the ways of reaching different fuel types and this is related to expenditure per capita for energy consumption.

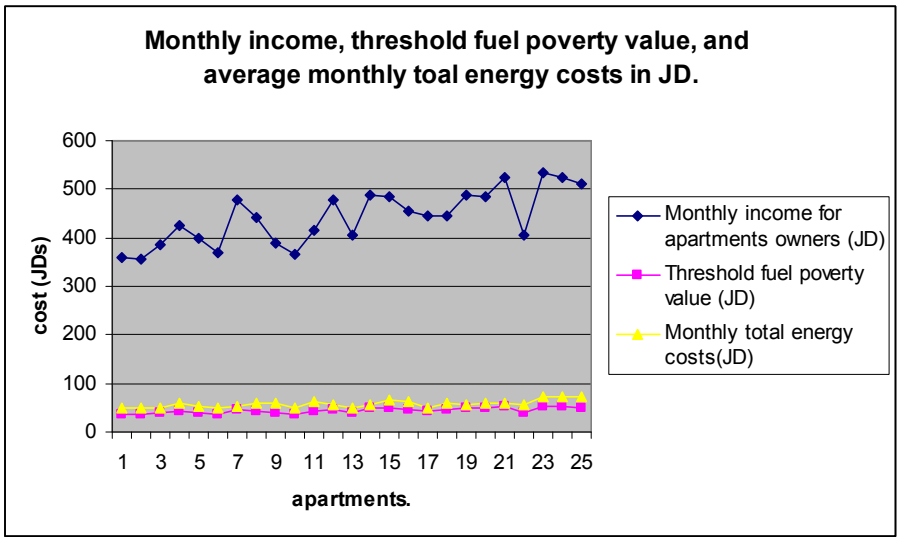

Fig. 3 Relationship between monthly income, average total energy costs and threshold fuel poverty value (JD).

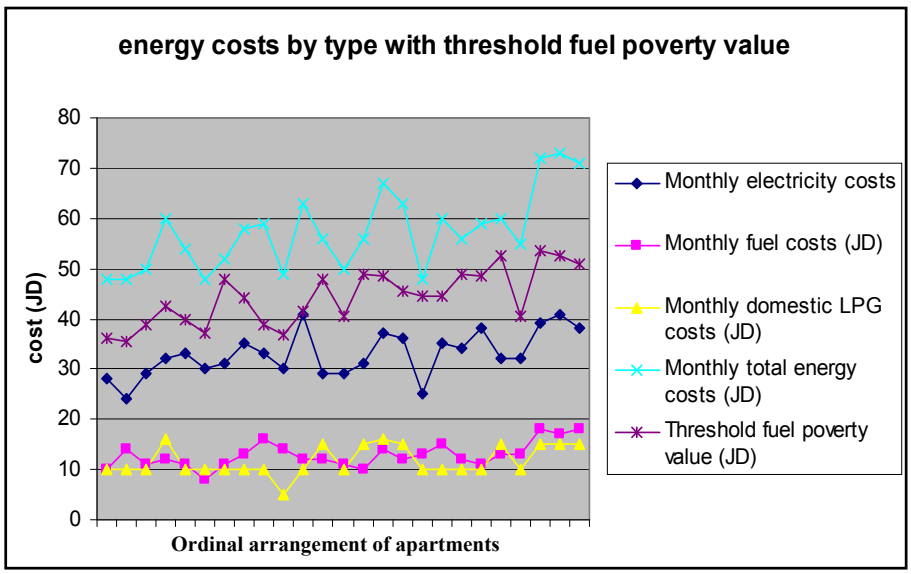

Fig. 4 Total energy costs arranged by type: electricity, fuel, domestic LPG.

In this context, it is important to be aware of the fact that utilization of renewable energy resources is a must. And there should be policy strategies for public awareness about energy consumption savings on both national and personal level.

Further studies must be implemented to explore the facts about fuel poverty lines for other home owner categories, unless this step is made, there is still something missing about fuel poverty line, and this shortage in implementing more work about this will not enable the government to draw policies about energy consumption, supply and management in Jordan.

At this end, one can draw a poverty line for households in Jordan based on real energy consumptions per capita of households, an issue which will enable policy makers to draw policies about how to shift such line and to exclude households from being under the line of fuel poverty.

Research remains open for investigating effects of family size and composition on energy use patterns in households in Jordan and probable increase in

consumption during the coming 20 years, and this will remain a rich research field.

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Faults and Claims about Thermal Environments in Relation to Energy Saving Measures in Smaller Office Buildings

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Abstract: Building equipment, energy-saving systems, and claims of inappropriate indoor thermal environments were analyzed in relation to the floor area using responses to a questionnaire survey of service managers of 157 buildings built in Osaka, Kyoto and Hyogo prefectures in Kinki area of Japan. Results show the following: (1) In smaller buildings (< 5,000 m^2), setting temperatures are higher in summer and lower in winter, effects of "uncomfortable radiation from windows" are greater, energy-saving systems decrease indoor thermal comfort, but claims of "hot" and "cold" are fewer; (2) Claims of "hot" and "cold" are unrelated to the setting temperature and whether the air-conditioning control system is central or local; (3) The adoption rates of mitigation of dress codes ("COOL-BIZ" and "WARM-BIZ") are higher than those of temperature mitigation of air conditioning.

Key words: Smaller office buildings, energy management, energy saving measures, COOL-BIZ, user claims of hot and cold.

1. Introduction

The energy saving regulation code in Japan was enforced in 1973. The national government revised the regulation several times and imposed more and more severe energy saving requirements and CO_2 emissions decreases on building owners and builders. As one revision in 2009, the buildings for which builders are obligated to report energy saving methods to the government, both for newly built and reformed areas, were reclassified to 300 m^2 from 2,000 m^2. The measure was aimed at more precise regulation of smaller buildings.

Areas of about 40% of the office buildings were less than 2,000 m^2 in 2003 in Japan. About 60% are smaller than 5,000 m^2. The actual situation of energy consumption and energy management of smaller buildings has, however, remained unclarified. Surveys of energy management on advanced buildings have been conducted, but the examined buildings were larger in scale.

Government reports show that CO_2 emissions are decreasing in the industrial and transportation sectors. Emissions of the industrial sector in 2009 were 19.5% lower than those of 1990. Emissions of the transportation sector in 2009 were 5.5% higher, but they have shown a decreasing trend since 2000. Emissions increased by 31.2% and 26.9%, respectively, in business and residential sectors, although the Kyoto Protocol obligated Japan to reduce CO_2 emissions by 6% in 2008-2012 compared with those in 1990. The national government carried out COOL-BIZ campaign in 2005 responding to the effect of the Kyoto Protocol. The campaign proposed setting air-conditioning temperature at 28^o along with dress code mitigation such as open-necked shirts. WARM-BIZ campaign proposing 20^o also started.

Surveys of energy management of smaller office buildings were conducted in 2009 by the Kinki branch of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan [1-11]. Based on analyses

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of the questionnaire surveys, this paper presents analyses of the relation of building equipment and energy saving measures to the occurrence of faults and claims about thermal environments in relation to building size.

2. Methods

2.1 Survey

Questionnaire sheets were sent to building maintenance managers of office buildings through the Osaka Building Owners and Managers Association founded in 1930 with about a 150 major building companies in Kinki area.

Both owner-occupied buildings and tenant buildings were included. Respondents were general managers of the owner building companies and staff members of outsourcing companies well informed about the building equipments. The survey, which was conducted in January 2009, yielded 157 complete responses [3, 6].

2.2 Questionnaire Items

Questionnaire items are the following: (1) fundamental attributes of the building such as size, age, stories, ownership and building use; (2) building equipment including heat sources, air-conditioning and ventilation systems; (3) building equipment operation methods; (4) energy saving measures including both those adopting more efficient apparatus or newest developed systems and management operation methods such as mitigation of air-conditioning temperature, turning off of equipment, mitigation of dress codes, which governments call COOL-BIZ in summer and WARM-BIZ in winter; (5) setting temperatures of air-conditioning equipment in each season; (6) occurrence of faults and claims from occupants relating to indoor climate. Acknowledgement of the revision of energy saving regulations and its effects on building management, recognition of energy performance of the buildings, history, and planning of reform of the buildings, the way to levy energy charges from tenants, and measured items of indoor environments are also surveyed.

3. Results and Discussion

3.1 Fundamental Attributes of the Buildings

Of the building sites, 77 are in Osaka prefecture, 16 in Hyogo prefecture, and 10 in Kyoto prefecture. Of the surveyed buildings, 96.5% are built in the Kinki area around Osaka prefecture. Regarding their age, 28 were built before 1970, 33 were built during 1970-1979, 34 were built during 1980-1989, 37 were built during 1990-1999, and 14 were built in 2000 or after. Regarding their respective heights, 57.0% are under five stories and 29 have three stories. Only 15 buildings are of over 11 stories.

Fig. 1 shows the area distribution of the buildings: 93 of the buildings are smaller than 5,000 m^2, 58 are 5,000 m^2 or larger. For six buildings, no response indicating the area was given. Mean office area per person is 10.5 m^2 for smaller buildings and 13.8 m^2 for larger buildings. Occupant density is not related to building floor area and building age.

3.2 Building Equipment

Types of heating systems and numbers of buildings that adopted them are as follows. 10 several types of responses might be given for a building: water-cooled chillers, 14 boilers, 28 air-cooled heat pump chiller, 86 air-cooled electric heat pump of multi-room systems by switching heating and cooling, 12 air-cooled electric heat pump of multi-room systems for both heating and cooling, 20 air-cooled gas heat

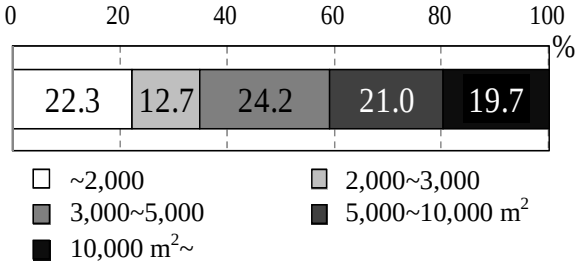


Fig. 1 Building floor area.

pump multi-room systems by switching heating and cooling, 4 air-cooled gas heat pump of multi-room systems for both heating and cooling, 2 water-cooled heat pump, and 40 gas boiled absorption refrigerating machine.

Types of air-conditioners and numbers of adopting buildings are 80 air ducted systems, 33 ducted fan coil unit systems, 66 packaged air-conditioners (cassette), and 34 packaged air-conditioners (concealed).

Types of ventilation systems and numbers of adopting buildings are those supplying air using air-conditioners and exhausting air by 69 electric fans, introducing and exhausting air by 56 heat exchangers, supplying and exhausting air by 25 electric fans, and those exhausting air by 29 electric fans.

Fig. 2 shows the relation between building equipment and building size. Smaller buildings are defined in this study as smaller than 5,000 m^2 in total area. Figures in parentheses following the equipment type show the percent significant level of Chi-square tests between smaller and larger buildings. Gas boiler absorption refrigerating machines tend to be adopted by larger buildings (P = 1%). No significant difference is found by building size in other heat source systems.

Fan coil unit systems tend to be adopted in larger buildings (P = 1%). No difference is found by building size in adopting duct systems and using packaged air-conditioners.

Ventilation systems with exhausting electric fans tend to be adopted in smaller buildings (P = 1%). Ventilation systems with supplying and exhausting electric fans tend to be adopted in larger buildings (P = 1%). No significant difference is found according to building size in the other two ventilation systems.

3.3 Energy Saving Measures

Energy saving systems for lighting and numbers of adopting buildings are as follows: 51 high-frequency lighting fixtures, 33 automatically actuating devices for sensing occupancy, equipment turned on and off by 3 timers, and brightness tuning apparatus by 7 sensing illuminance.

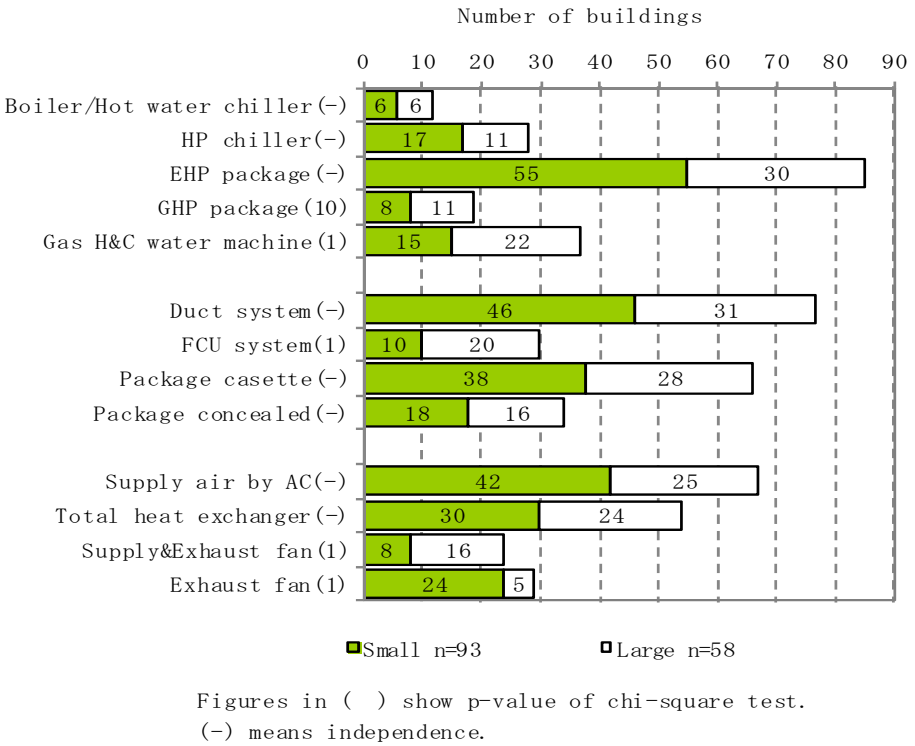


Fig. 2 Relation between building equipment and building size.

Energy-saving systems for air-conditioning and numbers of adopting buildings are as follows: 18 high-efficiency apparatus, 63 total heat exchangers, 23 variable air volume controllers, 10 variable water volume controllers, 20 outdoor air cooling, 14 natural ventilation systems, air volume control by 7 sensing indoor carbon dioxide density, supply air volume control into lavatories by 1 sensing occupancy, 30 heat storage systems, packaged air-conditioner controls by 9 electric power demand, and water spray on 2 outdoor units.

Energy saving measures related to operation and numbers of adopted buildings are as follows: 80 air-conditioning setting temperature mitigation for whole buildings, 24 air-conditioning setting temperature mitigation for common spaces of buildings, 46 time limits of air-conditioning (turning off for overtime work or in natural ventilation season), and dress code mitigation, COOL-BIZ or WARM-BIZ 108.

Numbers of buildings adopting solar generation are 8, co-generation systems are 2, water saving apparatus are 39, and rainwater use systems are 12.

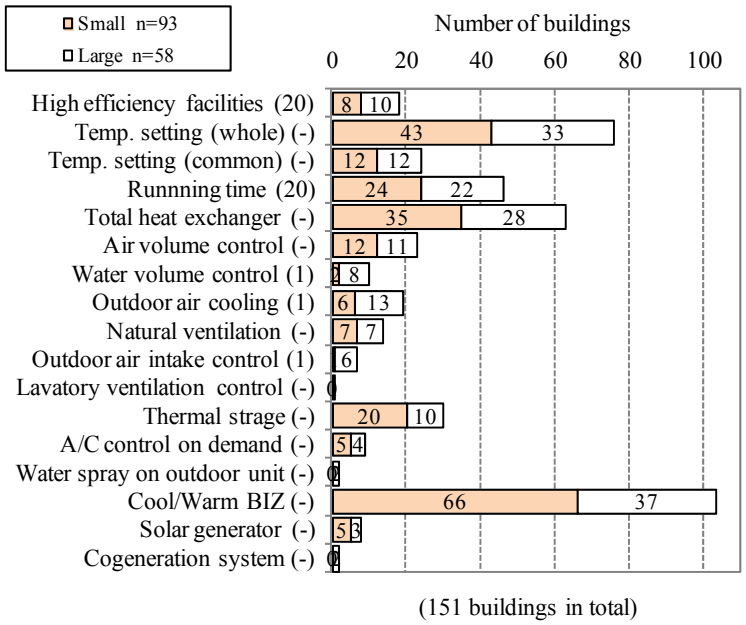
Fig. 3 shows energy saving measures in relation to the building size. Variable water volume controllers, outdoor air cooling, and supply air volume control are adopted in larger buildings (P = 1% for each). No difference is found in the ratio of adoption for other measures.

3.4 Setting Temperature

Fig. 4 portrays a frequency distribution of setting temperatures for smaller buildings (< 5,000 m^2) and larger buildings. In summer, 26 ^oC is the setting in 43.5% and 28 ^oC is the setting in 45.7% in larger buildings, although 28 ^oC is the setting 67.6% in smaller buildings. In winter, 19 ^oC is the setting in 6.4% in larger buildings, although it is 30.0% in smaller buildings. Setting temperatures in smaller buildings are higher in summer and lower in winter.

3.5 Setting Temperature Mitigation and COOL-BIZ or WARM-BIZ

Fig. 5 shows ratios of adoption of setting temperature mitigation and BIZ (COOL-BIZ or WARM-BIZ). Adoption of setting temperature mitigation and BIZ are not related to building size, as noted before. The figure shows that the adoption of



(151 buildings in total)

Fig. 3 Energy saving measures and building size.

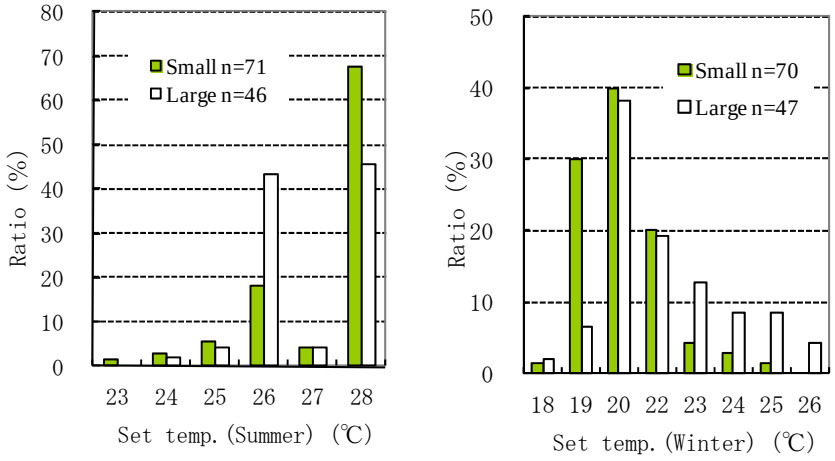


Fig. 4 Setting temperature of air-conditioning in smaller and larger buildings.

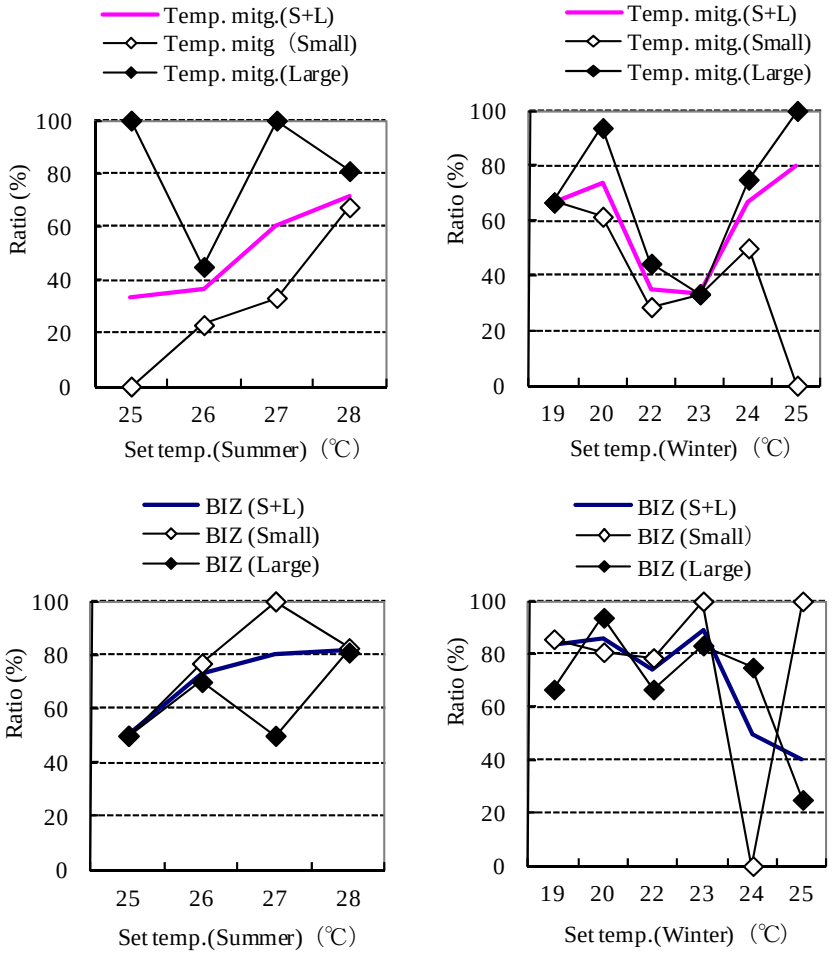


Fig. 5 Ratios of adoption of setting temperature mitigation and COOL-BIZ or WARM-BIZ.

BIZ is unrelated to the building size for each setting temperature. However, the ratio of setting temperature mitigation is higher in larger buildings than in smaller buildings in summer. The figure also shows that the ratio of BIZ is higher than those of temperature mitigation for each setting temperature. This result shows that some buildings adopt only BIZ without temperature mitigation.

3.6 Faults and Claims from Occupants Related to Indoor Climates

Faults and claims related to lighting and the numbers of buildings with claims are as follows: darkness in 2 work spaces, darkness in 2 common spaces, and 17 division of spaces with and without lighting.

Faults and claims relating to air-conditioning and the number of buildings claimed are as follows: hotness in 47 work spaces, coldness in 33 work spaces, 23 vertical temperature difference, 22 horizontal temperature difference, 31 division of space for conditioning on and off, 28 division of space for temperature control, 4 infiltration, 23 window radiation, hotness in 8 common spaces, coldness in 9 common spaces, high humidity in 1 work space, low humidity in 21 work spaces, 6 draft, and 7 air-conditioning noise.

3.7 Claims of "Hot" and "Cold" and Building Size

Fig. 6 shows the relation between faults and claims and building size. Faults and claims occur in relation to the thermal environment. For example, 43 buildings are reported as "hot in the work space" and 29 are reported as "cold in the work space". However, faults and claims related to air movement and noise are fewer. 39.7% of larger buildings are "hot" and 31.0% are "cold". Faults and claims of "hot" and "cold" occur in larger buildings at about as twice and three times the rates as in smaller buildings, respectively (P = 2% and 1%, respectively). No difference is found in the ratio of occurrence for other faults and claims other than "hot" and "cold".

3.8 Setting Temperature and Claims of "Hot" and "Cold"

Fig. 7 shows the ratios of occurrence of "hot" and "cold" for each setting temperature. The ratio of "hot" is 36.4% for 26 ^{o}C and 25.4% for 28 ^{o}C in summer. The ratio of "cold" is 12.5% for 19 ^{o}C and 21.4% for 20 ^{o}C in winter. No significant difference is found in the setting temperature in summer (in winter) between occurrence and not occurrence of "hot" ("cold") in larger or smaller buildings. It can be defined that the setting temperature is not so related to the occurrence of claims of "hot" and "cold".

3.9 Non-uniform Thermal Environment and Claims of "Hot" and "Cold"

Table 1 presents the P values of uniformly consistent tests among claims relating to thermal environment

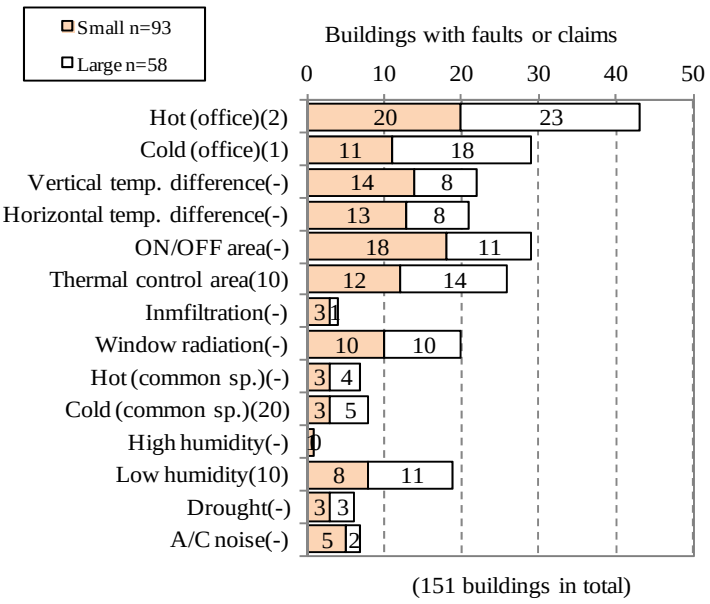


Fig. 6 Relation between faults and claims and building size.

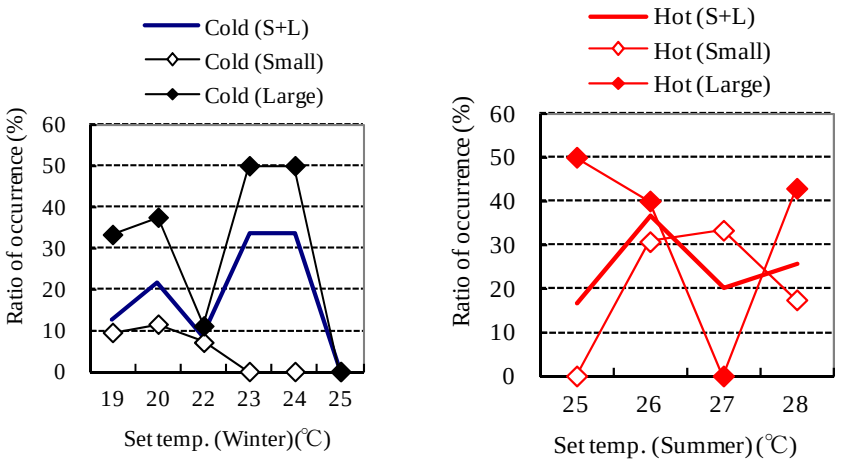


Fig. 7 Relation between setting temperature and occurrence of claims of "hot" and "cold" in smaller and larger buildings.

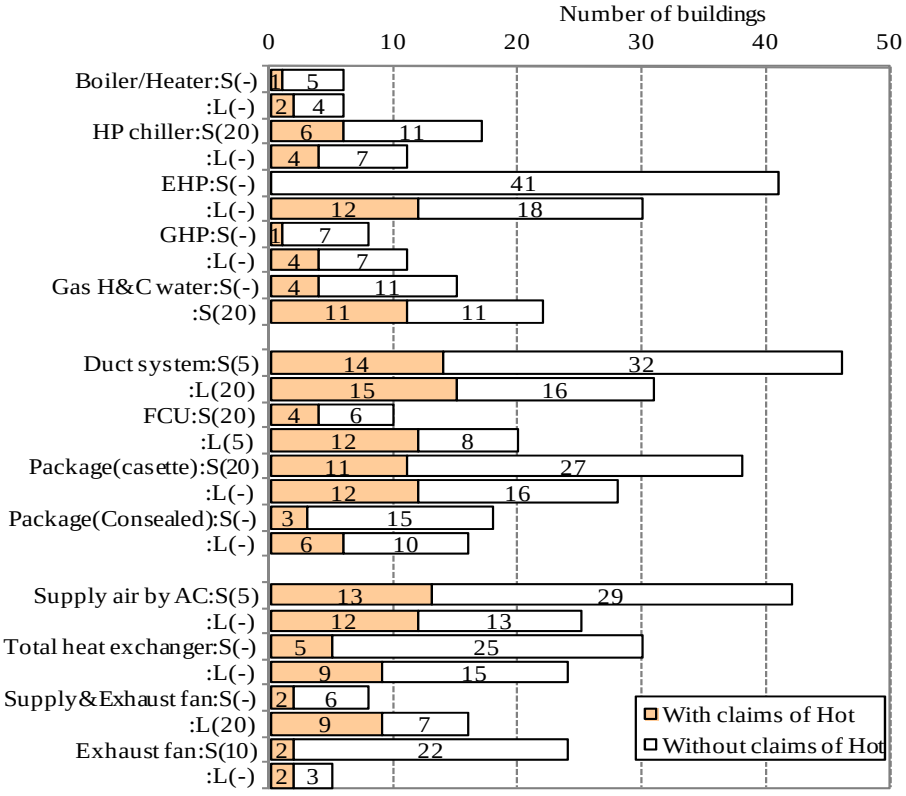
Table 1 Faults and claims of thermal environment in smaller and larger buildings.

Claims	Buildings	*n*	Hot (*P*%)	Cold (*P*%)	Vert. (*P*%)	Horiz. (*P*%)
Hot	L + S	43				
	Large	23				
	Small	20				
Cold	L + S	29	1			
	Large	18	1			
	Small	11	1			
Vertical temp. difference	L + S	22	-	-		
	Large	14	-	-		
	Small	8	-	-		
Horizontal temp. difference	L + S	21	20	20	1	
	Large	13	20	20	1	
	Small	8	-	-	1	
Radiation from windows	L + S	20	1	1	5	5
	Large	10	5	1	20	20
	Small	10	1	20	20	20

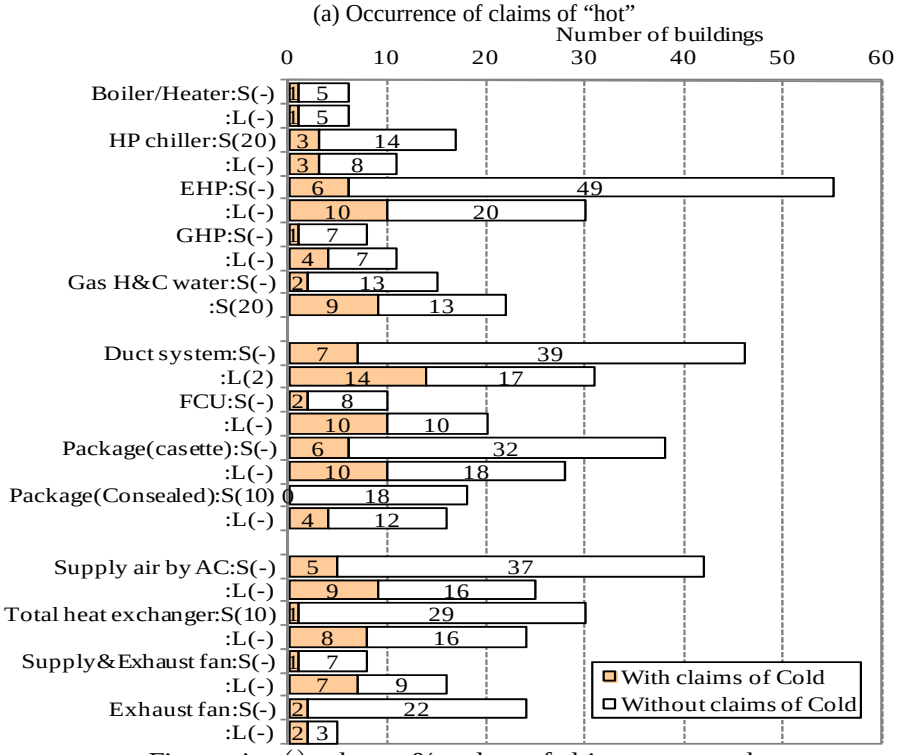
for each building size. The "vertical temperature distribution" is not related to "hot" and "cold" for each size of building, although it is related to the "horizontal temperature distribution" (P = 1% for each). It can be defined that the "vertical temperature distribution" and "horizontal temperature distribution" tend to occur at the same time irrespective of the building size but are not so related to claims of "hot" and "cold".

However, "improper radiation from windows" is related to "hot" and "cold" in smaller buildings (P = 1%, 2%) and larger buildings (P = 5%, 20%). That fact indicates that radiation from windows tends to cause to be "hot" and "cold" only in smaller buildings.

No difference is found among numbers of workers in typical office rooms between smaller and larger buildings. In more than half of the buildings, 40 workers work in an office room. It is presumed that vertical and horizontal temperature differences occur because the room is large but differences are not sufficiently large to provoke claims of being "hot" or "cold". However, irradiation from windows occurs even if office rooms are large. It affects workers near windows, causing claims of the room being "hot" or "cold".



(a) Occurrence of claims of “hot”



Figures in （） show p%-values of chi-square tests between adoption of equipment and occurrence of claims of Hot or Cold. (-) mean independence.

(b) Occurrence of claims of “cold”

Fig. 8 Relation between building equipment and occurrence of claims of “hot” (a) and “cold” (b) in smaller and larger buildings.

3.10 Building Equipment and Claims of "Hot" and "Cold"

Fig. 8 portrays the relation between numbers of claims of "hot" and "cold" and building equipment in smaller and larger buildings.

Heat source systems and ventilation systems are unrelated to the occurrence of "hot" and "cold" for all building sizes. Both "hot" and "cold" claims occur more frequently for fan coil unit systems in larger buildings (P = 5% for each). However, fan coil unit systems are not related to "hot" and "cold" claims in smaller buildings. Both "hot" and "cold" claims occur more frequently for buildings with duct systems for all buildings (P = 2% each, figure is omitted).

Packaged air-conditioners are not related to "hot" and "cold" in either smaller or larger buildings, but there are no "cold" buildings among smaller buildings with packaged air-conditioners (concealed) (P = 10%).

More than one type of air-conditioning system is sometimes adopted. Buildings with only duct systems or only with fan coil unit systems are 44, with only packaged air-conditioners are 37, and those with duct or fan coil unit systems for some rooms and packaged air-conditioners for other rooms are 48. Adoption of a type of air-conditioning in these tree types is independent of the building size. "Hot" claims occur more frequently for the third type in smaller buildings (P = 1%).

Air-conditioning operation methods such as a change of temperature and turning on and off are as follows. Buildings with individual operation by occupants are 78. Centrally operated buildings in which occupants are unable to operate air-conditioners, with operation by building managers, scheduled operation by timers, and remotely controlled operation from other buildings are 33. Adoption of a type of operation in these two types does not depend on the building size. "Hot" is claimed more frequently and "cold" occurs less frequently in centrally operated buildings (P = 5% and 10%, respectively). Methods of air-conditioner operation are unrelated to the occurrence of "hot" and "cold".

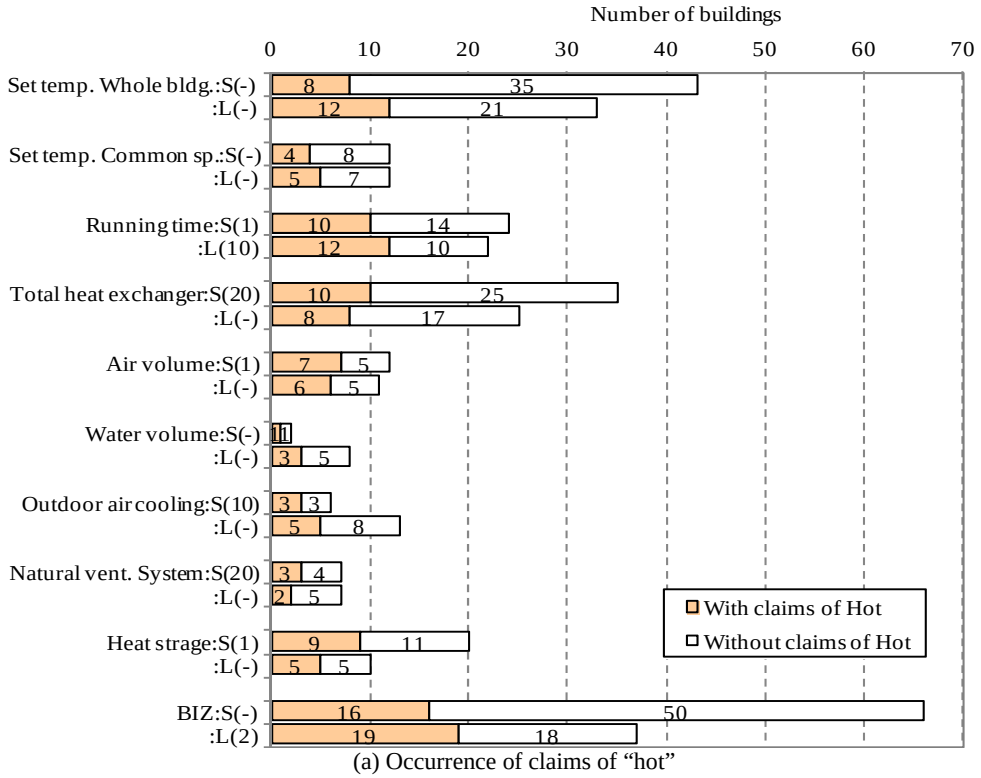
3.11 Energy Saving Measures and Claims of "Hot" and "Cold"

Fig. 9 presents the numbers of buildings with claims of "hot" and "cold", along with energy saving measures. Adoption of "limitation of running time of air-conditioning", "variable air volume", and "heat storage system" are related to "hot". Adoption of "variable water volume" and "outdoor air cooling" are related to "cold" in smaller buildings (P = 1% for each). Faults and claims of the thermal environment might result from adoption of these energy saving measures in smaller buildings. However, energy saving measures are unrelated to thermal environments in larger buildings, except for adoption of BIZ, for which "hot" occurs more frequently (P = 2%).

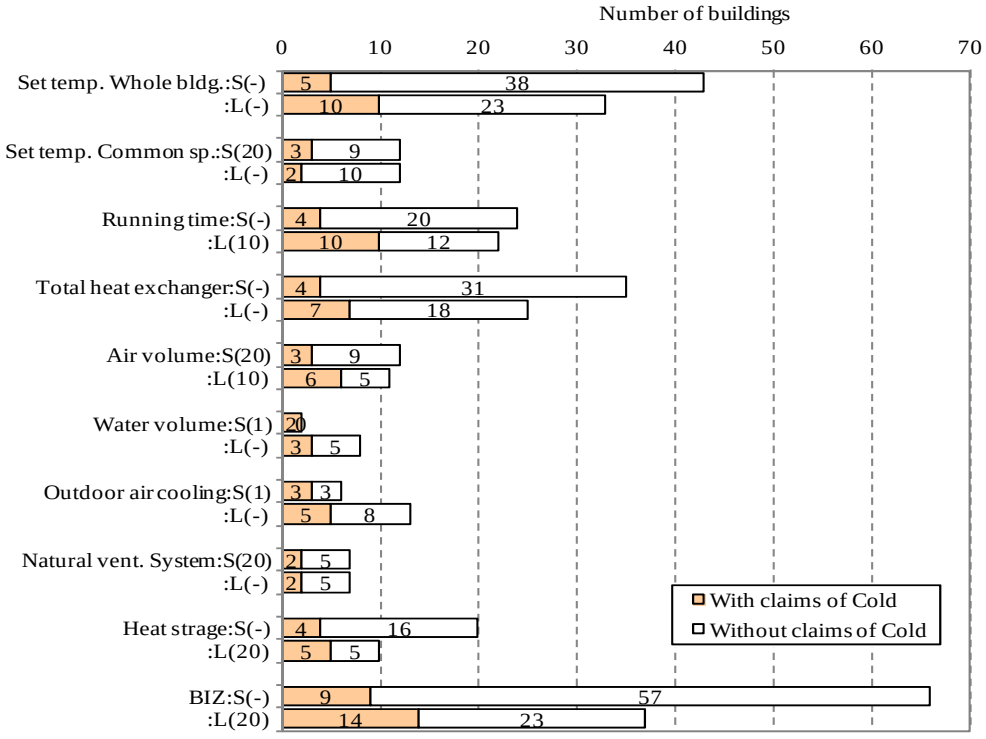
4. Discussion

Set temperatures are higher in summer and lower in winter in smaller buildings. In summer, 28 ^{o}C is the setting of 67.6% of smaller buildings. In larger buildings, 26 ^{o}C was the setting in 43.5% and 28 ^{o}C was the setting in 45.7%. In winter, 19 ^{o}C was the setting in 6.4% in larger buildings, although it was 30.0% in smaller buildings. It can be defined that occupants in smaller buildings are in a poor thermal environment. Differences of financial circumstances of building owners, such as size of capital and capacity for borrowing are inferred as underlying causes of these results.

Faults and claims related to air movement and noise are fewer, those of thermal environments occur more often. Those of "hot" and "cold" occur respectively in 39.7% and 31.0% of larger buildings. However, faults and claims of "hot" and "cold" occur less frequently in smaller buildings, at about a half and a third



(a) Occurrence of claims of "hot"



Figures in () show p%-values of chi-square tests between adoption of energy saving measure and occurrence of claims of Hot or Cold.
(-) means independence.

(b) Occurrence of claims of "cold"

Fig. 9 Relation between energy-saving measures and occurrence of claims of "hot" (a) and "cold" (b) in smaller and larger buildings.

respectively, irrespective of the air-conditioning temperature setting.

The ratios of occurrence of "hot" and "cold" for each setting temperature were assessed. The ratio of "hot" was 36.4% for 26 ^{o}C and 25.4% for 28 ^{o}C in summer. The ratio of "cold" is 12.5% for 19 ^{o}C and 21.4% for 20 ^{o}C in winter, with no significant difference between the setting temperature and the occurrence of "hot" and "cold".

To investigate the difference of claims of "hot" and "cold" by building size, effects of non-uniform thermal environments such as vertical and horizontal temperature difference and radiation from windows on the difference of occurrence of "hot" and "cold" by building size were assessed. Thermal environments depend on non-uniform thermal radiation from windows rather in smaller buildings. "Improper radiation from windows" is related to "hot" and "cold" in smaller buildings (P = 1%, 2%). That relation shows that occupants of smaller buildings might sit near windows. Environments might increase claims of "hot" and "cold" in smaller buildings, but the reverse is true.

Effects of building equipment were also investigated. Heat source systems and ventilation systems are unrelated to "hot" and "cold" for all building sizes. Both "hot" and "cold" claims occur more frequently for fan coil unit systems in larger buildings (P = 5% for each), but fan coil unit systems are unrelated to "hot" and "cold" in smaller buildings. Package air-conditioners are unrelated to "hot" and "cold" in smaller and larger buildings. Buildings having only duct systems, those with only fan coil unit systems, and those with only package air-conditioners are compared, but the type of air-conditioning operation is independent of the building size.

Effects of energy-saving measures on "hot" and "cold" were also assessed. Energy-saving measures are related to "hot" and "cold" rather more in smaller buildings. "Limitation of air-conditioning running time", "variable air volume", and "heat storage system" are related to "hot" and "variable water volume" and "outdoor air cooling" are related to "cold" in smaller buildings. It can be said that faults and claims related to thermal environments might result from adoption of these energy-saving measures in smaller buildings. However, energy-saving measures are unrelated to the occurrence of "hot" and "cold" in larger buildings, although adoption rates of energy saving measures are not significantly different between smaller and larger buildings.

Results clarify that claims of "hot" and "cold" are fewer in smaller buildings despite the poorer thermal environments. Fewer claims are unrelated to a difference in setting temperature, non-uniform thermal environments, building equipment, and adoption of energy-saving measures. Additional investigations are needed, but the difference might be attributable to thermal control measures by occupants. Occupants in smaller buildings sit near windows. They have good access to thermal control through windows. Differences in claim-gathering systems must also be considered. Occupants of smaller buildings might have fewer means to bring claims.

5. Conclusions

Results of the survey reveal that smaller buildings (< 5,000 m^2) present difficulty in regulating thermal environments as follows. Setting temperatures are higher in summer and lower in winter in smaller buildings. Thermal environments depend on non-uniform thermal radiation from windows in smaller buildings. Energy conservation measures sometimes cause claims of "hot" and "cold" in smaller buildings. Nevertheless, faults and claims of "hot" and "cold" occur less frequently in smaller buildings than in larger buildings.

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Experimental Verification to Estimate Ground Thermal Conductivity Using Spiral Coil Type Ground Heat Exchangers

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Abstract: This paper presents an experimental study on the evaluation of thermal response of a spiral coil type GHE (ground heat exchanger). This GHE was installed on partially saturated landfill ground that was composed of silt and clay in the runway area of Incheon International airport. TRT (thermal response test) was conducted for more than 65 hours under continuous operation conditions. Ground thermal conductivity was derived based on line source theory, which has usually been found to be appropriate for line type GHEs such as U, W and 2U types. A reasonable method to derive ground thermal conductivity using the infinite line source theory for a spiral coil type GHE was introduced. Ground thermal conductivity from the TRT using spiral coil type GHE was compared with those from the analytical equivalent model of ground thermal conductivity.

Key words: Ground thermal conductivity, ground heat exchanger, thermal response test, spiral coil.

1. Introduction

The need for renewable energy sources is constantly increasing with the advent of global warming and depletion of fossil energy. Geothermal energy has great potential to provide directly usable energy, especially in connection with ground sources or GCHP (ground-coupled heat pump) systems. GCHP systems use the ground as a heat source as it provides a relatively constant temperature. They release heat energy in summer while they absorb heat energy in winter. Agriculture also can use a GCHP system for heating and cooling of a greenhouse. Since heat demands from greenhouses are more complex than those for residence buildings, greenhouses are strongly affected by weather conditions. For that reason, GCHP systems for greenhouses require accurate estimation of ground thermal properties. GCHP systems can be categorized into open or closed systems. Open systems exchange heat to/from aquifer water, closed systems exchange heat to/from the ground by circulating fluid in heat exchange pipes. Closed systems can be largely divided into vertical and horizontal types. A horizontal system requires the installation of a large volume of GHEs (ground heat exchangers) at shallow depth, necessitating a large land area. A vertical system has high initial construction costs as a borehole of up to tens or hundreds of meters has to be installed. As an alternative, the application of energy piles, which utilize piles under a raft foundation, has recently been expanded [1]. This system has the advantage of affordable initial investment costs, it does not require additional construction costs during the construction process. Compared to conventional vertical type systems, the energy pile has a larger diameter and shorter length. In Korea, most energy piles have relatively short length of less than 20 m, because of the shallow depth of the bedrock location. For that reason, to compensate for the shallow installation

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depth of the energy pile, a spiral coil type GHE can be used to enhance the heat efficiency because such a device can increase the heat exchange area compared to U and W type GHEs [2].

Ground thermal conductivity is one of the most important factors in the design process of GCHP systems in the conventional vertical GHEs, as well as in energy piles [3]. The value of ground thermal conductivity can be derived simply by applying the infinite line source model with field TRT (thermal response test) results. However, it is not accurate to use the infinite line source model in spiral coil type GHEs [4]. Therefore, different kinds of analytical models adequate for spiral coil type GHEs have been introduced. These models are very complicated and make it inconvenient to derive the ground thermal conductivity. Accordingly, this paper introduces a simple method to derive the ground thermal conductivity from TRT results conducted in spiral coil type GHEs. The results were also compared with results for real ground thermal conductivity.

2. Theoretical Background

In GHE systems, heat is extracted from or released to the surrounding ground through a circulating fluid. The heat transfer mechanism of a ground heat exchanger is quite complex and conjugated because of the various heat transfer mechanisms involved inside and outside the GHEs. Soil is a multiple phase system involving complex heat transfer mechanisms, however, heat transfer in soils occurs mainly through conduction [1], whereby energy is passed from one region of a medium to another by molecular transfer. According to Fourier's law, the heat flux through an arbitrary area (A) during time (t) can be written as

$$q = \frac{Q}{At} = \frac{\dot{Q}}{A} = -\lambda \frac{\partial T}{\partial x} \tag{1}$$

where, λ is the thermal conductivity and $\partial T/\partial x$ is the temperature gradient. The GHE can be treated as a line source considering that the radius of a borehole is much smaller than its length. The change in ground temperature at a distance (r) from the line source after time (t), and the constant heat injection rate per active length of the borehole (q) can be approximated using the infinite line source model. The above equation can be applied to conditions in which L (heat source length)/D (heat source diameter) is larger than 25-30 [5].

$$T_{(r,t)} - T_{(t=0)} = \frac{q}{4\pi\lambda}\left(\ln(4\alpha t / r^2) - \gamma\right) \tag{2}$$

In this equation, γ is the Euler constant, which is normally 0.5772, and α is the ground thermal diffusivity. The error can be up to a maximum of 2.5% for $\alpha t/r^2 \geq 20$ and 10% for $\alpha t/r^2 \geq 5$ [6, 7]. By picking two points on the linear part of the curve of mean circulating fluid temperature, i.e., the average fluid temperature between the inlet and outlet-time in a semi-natural logarithmic scale under steady state conditions, the ground thermal conductivity can be approximately estimated using the following equation:

$$\lambda = \frac{Q}{4\pi L}\left(\frac{\ln t_2 - \ln t_1}{T_{f,av,2} - T_{f,av,1}}\right) \tag{3}$$

Soil in the ground is normally non-homogeneous, especially in the vertical direction along GHEs. An analytical equivalent model for multi-layered soil can be achieved using the following equation [8]:

$$\lambda_{eq} = \frac{(h_1\lambda_1 + h_2\lambda_2 + h_3\lambda_3)}{h_1 + h_2 + h_3} \tag{4}$$

3. Experimental Setup

A spiral coil GHE (Fig. 1) in the general vertical type system was installed in a partially saturated landfilled runway area of Incheon International Airport in South Korea. The spacing of the coil is 5 cm, the coil diameter is 28 cm, and the vertical depth is 30 m. Polybutylene pipe (inner/outer diameter of pipe = 0.016/0.02 m) was used for the GHEs, and bentonite grout was poured into the borehole. Fig. 2 shows the construction process of the vertical GHEs in the field. The ground was composed of silt, clay,

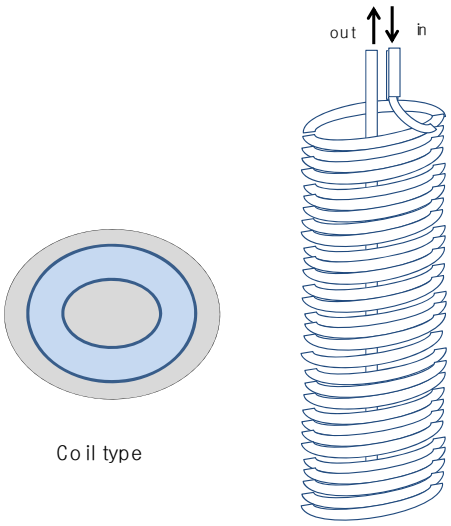
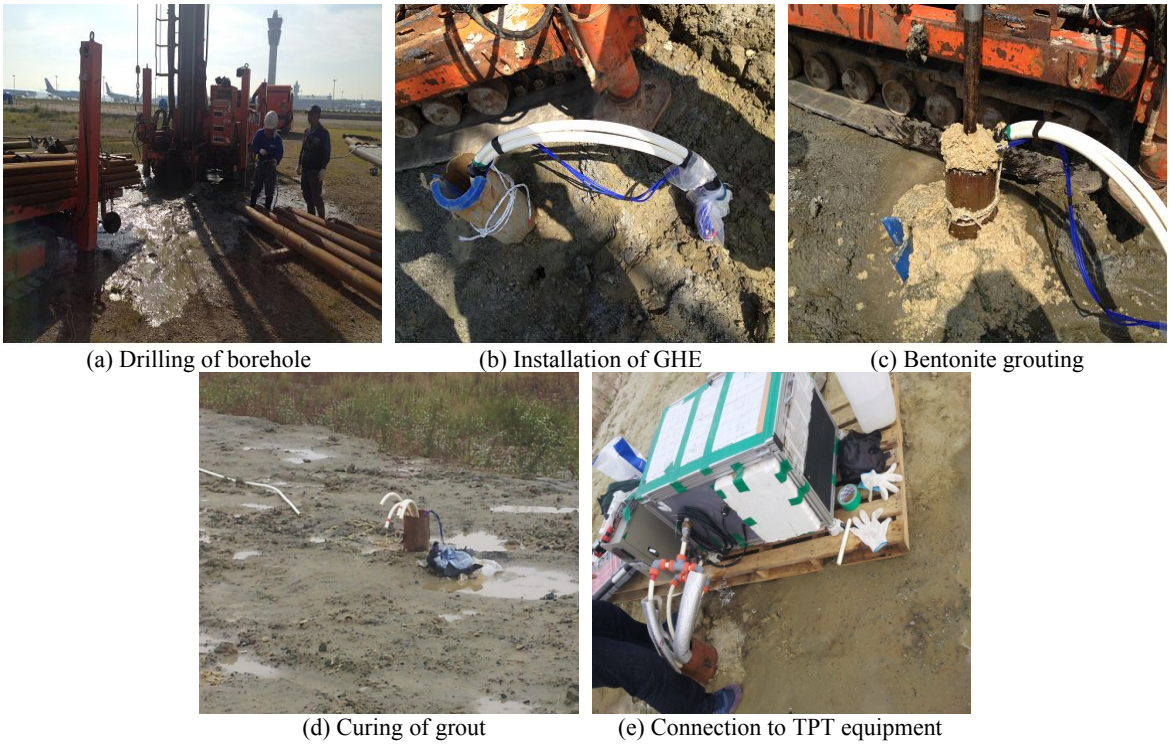


Fig. 1 Diagram of spiral coil type GHE.

weathered granite soil and weathered rock. Ground water level was 3.5 m below the top of the embedded borehole. The SPT (standard penetration test) N value was 9/30-33/30 in the partially saturated landfill ground, and weathered rock appeared 30 m below the ground level. The average void ratio was 0.95 and water content was between 30%-35%. The thermal conductivity of the landfill soil was measured using a TP-08 device (Hukseflux Thermal Sensors Inc.), based on the transient hot-wire method. Soil was remolded to have the same void ratio and water content as those of the construction site. The thermal conductivity of the silt-clay in the landfill area below the ground water table was measured and found to be 2.3 W/m·K. Since not all the layered soils were sampled, the thermal conductivity of the weathered granite soil was estimated to be around 2.4 W/m·K from the fitted model suggested by Park et al. [2] in order to derive the thermal conductivity of Korean granite soil. Table 1 shows basic ground thermal properties. The weighted average ground thermal conductivity value, considering each layer's ground depth, was found to be around 2.10 W/m·k using Eq. (4).

4. Results and Discussion

Constant heat flux was applied to the water tank using an electric heater, and TRT was conducted until a steady state condition was attained. Temperatures of water at the inlet and the outlet were monitored during



(a) Drilling of borehole (b) Installation of GHE (c) Bentonite grouting

(d) Curing of grout (e) Connection to TPT equipment

Fig. 2 Construction processes of GHE.

Table 1 Basic ground thermal properties.

Materials	Thermal conductivity (W/m·K)	Specific heat capacity (J/kg·K)	Density (kg/m³)
Soil 1	0.21	800	1,600
Soil 2	2.30	1,300	2,100
Soil 3	2.40	1,280	2,140

the test, and the flow rate was also measured at the outlet. Generally, in the case of a closed vertical type system, the thermal response test has to be conducted for over 48 h until the steady state condition is attained. However, in this experiment, the temperature of the circulating water only reached its normal state after 60 h, and hence the test was conducted for 65 h. Since the heat transfer of the spiral coil type GHE occurred easily in comparison with those of the U and W type GHEs, it took more time to reach the steady state. Heat-free water circulation was performed for 30 min to equalize the soil and circulating fluid temperature. The initial temperature of the soil due to the heat free water circulation was 16.14 ^{o}C, the temperature distribution was between 16.14-31.34 ^{o}C during the TRT. The average temperature difference between the inlet and the outlet was 5.6 ^{o}C. With the temperature value and the slope of $\Delta T/\Delta \ln t$, it was possible to evaluate the ground thermal conductivity using Eq. (3), the value was found to be 2.17 W/m·K. This value is very similar to the equivalent ground thermal conductivity derived using Eq. (4) at a depth of 30 m below the surface. As the value of L (heat source length)/D (heat source diameter) is almost 100, Eq. (3) can also be used to derive the ground thermal conductivity in the spiral coil type GHE. However, if the temperature values at just 48 h are used, the ground thermal conductivity, estimated using Eq. (3), is around 1.86 W/m·K. This is because TRT did not reach the steady state condition within 48 h. Therefore, the estimated ground thermal conductivity was not appropriate.

5. Conclusions

An experimental system for TRT in a spiral coil type GHE was established in the field. TRT was performed for the spiral coil type GHE in a partially saturated landfilled runway area of Incheon International Airport in South Korea. As the value of L (heat source length)/D (heat source diameter) is almost 100, the infinite line source model was applied to derive the ground thermal conductivity from the TRT results for the spiral coil type GHE. The estimated ground thermal conductivity was 2.17 W/m·K, this value was very similar to that derived using the analytical equivalent model of the ground thermal conductivity at a ground depth of 30 m. It was concluded that the ground thermal conductivity can be reasonably derived from TRT in a spiral coil type GHE. However, TRT should be continued until a steady state condition is attained. After that, the infinite line source model can be applied to the TRT results. It should be considered that TRT in a spiral coil type GHE should not be performed under the same conditions as those used for U and W type GHEs.

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Architectural Requirements for Improving Social Interactions in Subway Stations: An Evidence Based Design Approach

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Abstract: Environmental design is concerned with the function of people within an environment and their interactions. Subway stations spaces are important examples of public spaces that are in close connection with the social life of people. Also, the fact that the social interactions and relations between people and city environments are becoming indispensable for subway station space indicates that these spaces play an essential role in urban life. This paper addresses the result of a study conducted by the authors on the influential elements pivotal to the improvement of social interactions in subway stations. The theory of John Lang in Urban design with consideration of social interaction was considered in this study. The objective of the study was to identify the architectural requirements in improving social interaction between people and environment in subway station spaces according to an evidence based design approach. To do so, relevant literature in different disciplines, architecture, urban design, social sustainability and so on, were reviewed. Next, the most important environmental factors which contribute to human behavior in public spaces were derived and analyzed. Data of the study were collected via questionnaires filled out by the users of Tehran's subway stations. The collected data were analyzed and the architectural elements/requirements for improving social interactions were classified. The results of the study indicate that in the case of architectural requirements, contribution to the improvement of social interactions, design considerations for physical and mental safety, accessibility and lighting are the most important factors.

Key words: Social interaction, subway station, architectural requirements, evidence-based design, human behavior.

1. Introduction

The development of human societies, their increasing requirements toward bettering life, and the limitation of existing resources highlight the transportation need in countries. In this regard, reaching a faster, safer, cheaper and more convenient transportation system has been one of the most important goals of human societies for many years [1]. Today, new technologies have led to safer, more energy-efficient and environment-friendlier rail transportations. Subway stations, as one of the most important type in rail transportations, are in close relationship with the urban spaces and public life of people in cities. Stations create new user behaviors and requirements that cause them to be considered as one of the most critical issues in the field of architecture and urban planning [2]. Subway stations are settings where large numbers of unrelated people are forced to share the same space while waiting. As a result, even though subway stations are primarily designed as transportation nodes, they, by default, assume the secondary function as public spaces that a large number of city dwellers use.

There are two main approaches in relation to the principles of subway station design. First approach considers the subway station as a place which merely facilitates the transportation for the users. In this approach, the potential of space is limited to the

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functional purposes [3]. However, second approach, from a broader perspective, looks for creating a public space which improves the social interaction of the users [4]. According to this approach, evaluation of influential architectural factors which contribute to different aspects of human factors should be taken into consideration [5].

A station building, also known as a head house, is the main building of a passenger train station. Nasreazadani [6] indicated that the station is an environment which consists of a complex of official and residential buildings and the platforms that facilitates the transportation. Overall, according to the different definitions of subway stations, it can be described as an urban area which provides not only inner city transportation but also subway stations acts to connect the human beings to each other and improve their interaction with the urban environment. Lang [7] indicated that in public spaces, social behavior patterns and architectural space potentials are in close relationship to each other. Carmona et al. [8] believed that current stations are public urban places which should be considered as an area for improving the social interaction and social life of the citizens. According to Lang [7] and Carmona et al. [8], social interaction plays an important role in public spaces.

The close relationship between the subway network and social life promotes these stations' influence on the life of people socially, culturally and economically [9]. Furthermore, subway stations could organize the public spaces and improve the image of the city [10]. The study of environmental space qualities in subway stations is one of the crucial measures that contribute to increase the users' satisfaction. In this regard, the appropriate accessibility and safety should be taken into consideration [11]. Dusmiscevis and Sariyildiz [9] classified the characteristics of space qualities in subway stations in three different areas: functional, psychological and structural. Alavi and Ranjbar [12] indicated that architectural factors which contribute to human factors are categorized in physical, functional, and psychological sections. Dusmisevic and Sariyildiz [9] notified that design of subway stations should be in close relationship with the users' needs, abilities and limitations. Table 1 displays different ideas about the qualities of subway stations design consistent with human factors which have been classified in four different areas.

2. Objectives

Since subway stations play an important role of social life, their contribution to the human life should be investigated. Pace et al. [4], Dusmiscevis and Sariylidiz [9] and Salahshoor [3] highlighted the importance of the role of subway stations in improving social life in the city. Alavi and Ranjbar [12] studied some aspects of the role of entrances of Tehran subway stations from point of contribution to social life perspectives. According to this study, there are some problems in the social role of Tehran subway stations, some of which have been showed in Figs. 1-4. This study attempts to assess different subway stations in order to inform the architectural requirements which contribute to improvement of the social interactions in Tehran subway stations toward sustainability goals. In this regard, different architectural factors in specific subway stations in Tehran were considered. The information provided in this report could be

Table 1 Architectural factors in connection with human factors from different studies perspectives.

Category	Architectural factors
Safety/security	Safety [11], supervision, attendance of users' safety and comfortable.
Physical/functional	Accessibility, way finding, consideration of pedestrian movement [11], furniture, seating space, disabled people accessibility [13], distinction between pedestrian and driver flows [14].
Psychological/ interpersonal	Social interaction [4], intimate and friendly space, sense of place, nostalgia (Afsharnaderi, 2010).
Aesthetic	Proportion and harmony of the space, material and color [3], human body dimension, space flexibility [10], views and perspectives [9].

Fig. 1 Overcrowded space in Tehran subway station.

Fig. 2 Lack of design consideration in station's entrance.

Fig. 3 Lack of consideration of disabled people.

implemented in existing and future subway stations to promote a stronger social interaction toward ergonomic goals.

Fig. 4 Poor design of the station entrance.

3. Methods

Related literature reviewed journal articles and reports of studies in multiple disciplines—architecture, transportation, environmental design and environment psychology—were studied to identify the existing knowledge in subway station design from the human behavior perspective. Next, 146 users, according to sample size selecting [15], were asked to fill out a questionnaire to identify the major problems in Tehran subway stations. The questions in the questionnaire forms were seeking for finding the most important environmental factors which contribute to improving social interaction inside the subway stations. For instance, the users were asked to evaluate how much they agree or disagree with the association between lighting and social interactions. All questionnaire forms were filled out in different times (10 a.m. to 6 p.m.) on three different days (Monday, Wednesday and Friday) in the second week of June 2009. Six questionnaires were disregarded because the lack of reliability. The remaining 140 users consisted of 91 male and 49 female users with the mean age of 26.7 years old. Tehran subway network map was studied and analyzed to find the subway stations to be included in the study. The users were randomly selected in 1st, 2nd, 4th and 5th lanes of Tehran subway stations to make sure that all above ground and under ground stations were included (Fig. 5). The stations were

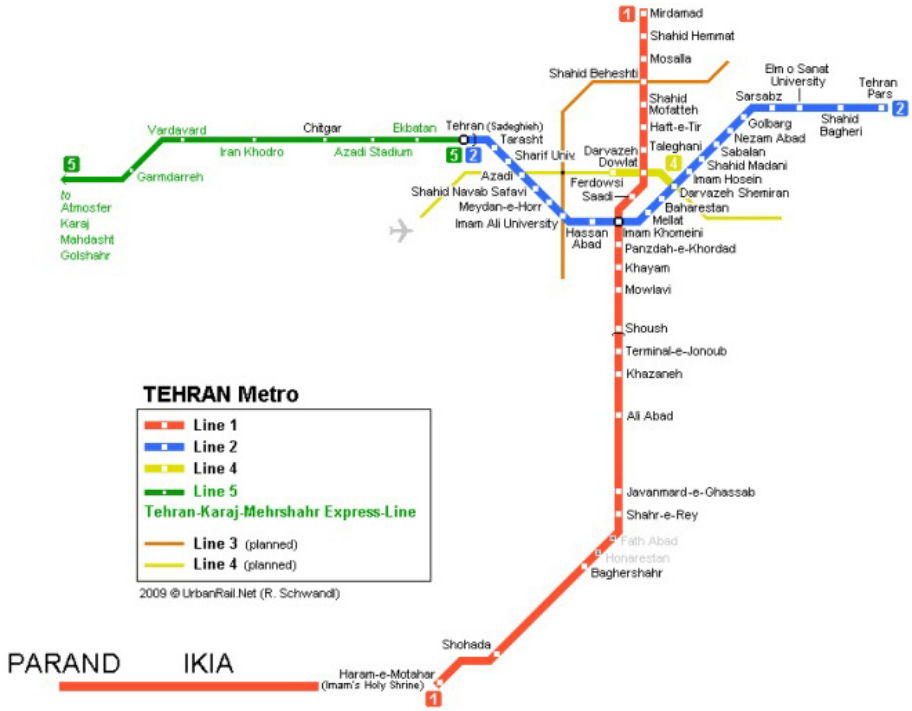

Fig. 5 The location and direction of different lanes of Tehran subway network.

observed by the authors and analyzed architecturally. Next, according to the data analysis and field studies in specific number of the stations, the problems and deficiencies of subway station design from the perspective of human factors were derived and concluded, and architectural requirements toward the improvement of social interaction in subway stations were indicated. The analyzed data were represented by graphic design and diagrams. In the final step, with the consideration of the results of the study, the proposed design solution of the subway station in Parand city was presented. According to the importance of the stations, the questionnaire forms were distributed between users. Sadeqieh station, because of its importance in connection to Karaj city and its greater size in comparison to other stations, had more users (18) to participate in the study. Additionally, Emam Khomeini station, as the central station and the main connection of first and second lanes had 15 users to participate in the study (Table 2).

The first, second, fourth and fifth lanes, as the main subway lines of public transportation in Tehran, were the settings of the study. Therefore, the stations in these two lines were the places that users were asked to fill out the questionnaires. Fig. 5 shows the location and direction of different lanes of subway network in Tehran [16].

Table 2 Classification of Tehran subway station according to the number of users participated in the study.

Station	Numbers	Station	Numbers	Station	Numbers	Station	Numbers
Shahid Madani	2	Sharif	2	Tehranpars	8	Azadi	5
Sadeqieh	18	Shahid Mofateh	1	Hasan Abad	2	Emam Hossein	4
Elmosanat	2	Tarasht	3	Haghani	3	Emam Ali	1
Fadak	1	Ali Abad	1	Darvazeh Shemiran	1	Baharestan	3
Qolhak	14	Farhangsara	9	Sarsabaz	3	Beheshti	1
Mosala	1	Golbarg	2	Mirdamad	16	Meidan Hor	9
		Emam Khomeini	15	Hemmat	1	Haft Tir	10

4. Findings

4.1 Problems in Tehran Subway Stations

One of the sections of the survey conducted in selected subway stations intended to reveal the main problems in subway stations. Overall, 67% of the respondents indicated that there are problems in subways stations. Field studies of the specific subway stations in Tehran and the results of the survey revealed some problems and deficiencies in the station spaces as following:

- overcrowded spaces inside and outside the station;
- weakness of social interaction between people and environment;
- unfriendly and cold environment;
- poor connection with the city and other public spaces;
- concentration on (moving) hallways and corridors rather than spaces for gathering and interacting;
- not suitable consideration for pedestrian at the main entrances;
- function instead the quality of space.

Although the limitation of finances for transportation paired with the growing number of users cause some of these problems such as the overcrowded spaces and long periods of time between arriving trains, remained unsolved, design intervention aligned with the human behavior can solve some of these problems and create better public space.

4.2 Architectural Factors and Human Factors in Subway Stations

In this step, users of Tehran subway network were asked to indicate which architectural factors can influence on social interaction in subway stations. To do so, the answers were collected in the Likert-type scale. Table 3 displays the users' answers. The results of this table indicated that the majority of users believe that these factors are influential in human factors of subway stations. In average, 44.67% of the users answered "Completely agree" and only 1.6% answered "Completely disagree". Among these factors, accessibility and safety (60%) have been described as the most influential factors.

N = Completely agree × (+2) + Agree × (+1) + Neutral × (0) + Disagree × (-1) + Completely disagree × (-2).

Next, the architectural factors in Table 1 were scaled and compared to each other. The results of the scaled factors are displayed in Fig. 6. The data were analyzed in the way that the score for each architectural factor was determined by adding the numbers of Completely

Table 3 Architectural factors and human factors in subway stations—users' perspectives.

Architectural factors	Completely agree (very positive) % (number)	Agree (positive) % (number)	Neutral % (number)	Disagree (negative) % (number)	Completely disagree (very negative) % (number)
Social interaction	30 (42)	44 (60)	16 (23)	7.8 (11)	2.8 (5)
Space attractiveness	50 (70)	32 (46)	7.8 (11)	7 (10)	2.8 (4)
Visual accessibility	51 (72)	32 (46)	7 (10)	8 (12)	0 (0)
Transparency	40 (57)	45 (64)	8.5 (12)	5 (7)	0 (0)
Accessibility	60 (84)	32 (46)	2.8 (4)	4.2 (6)	0 (0)
Noise	51 (71)	28 (40)	5 (7)	13 (19)	2.1 (3)
Lighting	50 (70)	42 (59)	4.6 (9)	1.4 (2)	0 (0)
Furniture (design and layout)	36 (51)	49 (69)	10 (14)	3.5 (5)	0.7 (1)
Artworks	40 (57)	33 (47)	20 (28)	5 (7)	0.7 (1)
Signs and symbols	37 (52)	46 (65)	10 (14)	5.7 (8)	0.7 (1)
Views and perspectives	30 (43)	30 (42)	25 (35)	12 (18)	1.4 (2)
Safety (physical and mental)	60 (85)	28 (40)	5.7 (8)	2.8 (4)	2.1 (3)

agree × (+2), Agree × (+1), Neutral × (0), Disagree × (-1), Completely disagree × (-2). In addition, Fig. 6 shows the interrelationships between architectural factors which affect social interaction in subway stations. The results from Fig. 6 indicated that safety (physical and mental), accessibility, and lighting are the most important factors which can contribute to improvement of social interaction in public subway stations.

These architectural factors are categorized in four different areas: security/safety, aesthetic, functional/physical, and psychological/interpersonal. The interrelationships between these factors were displayed in Fig. 7.

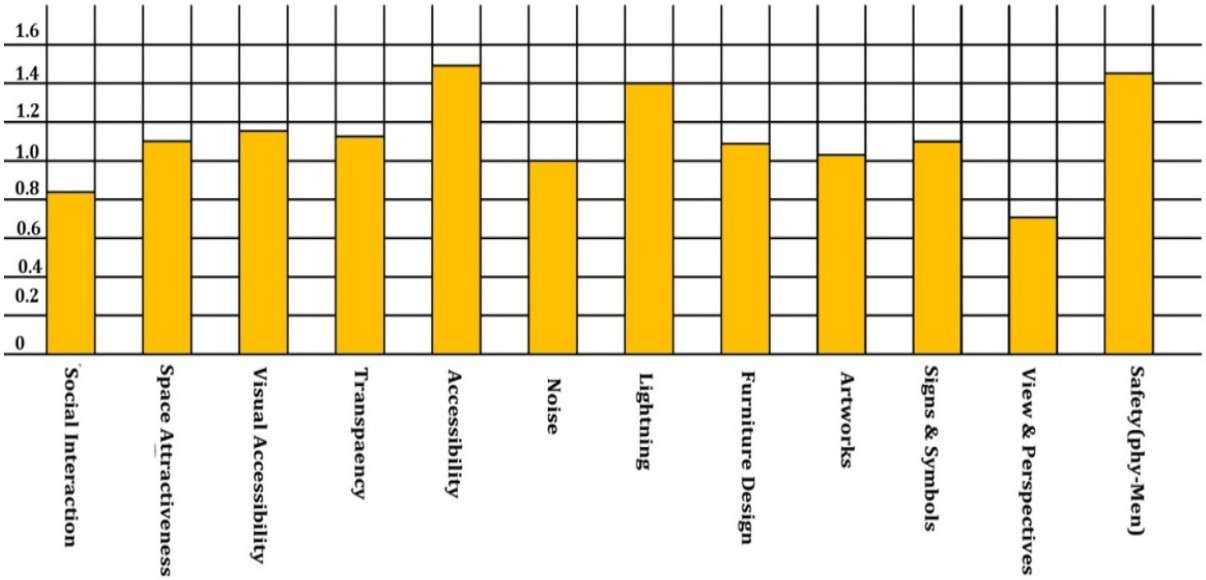

Fig. 6 Scaled architectural factors and human factors in subway stations—users' perspectives.

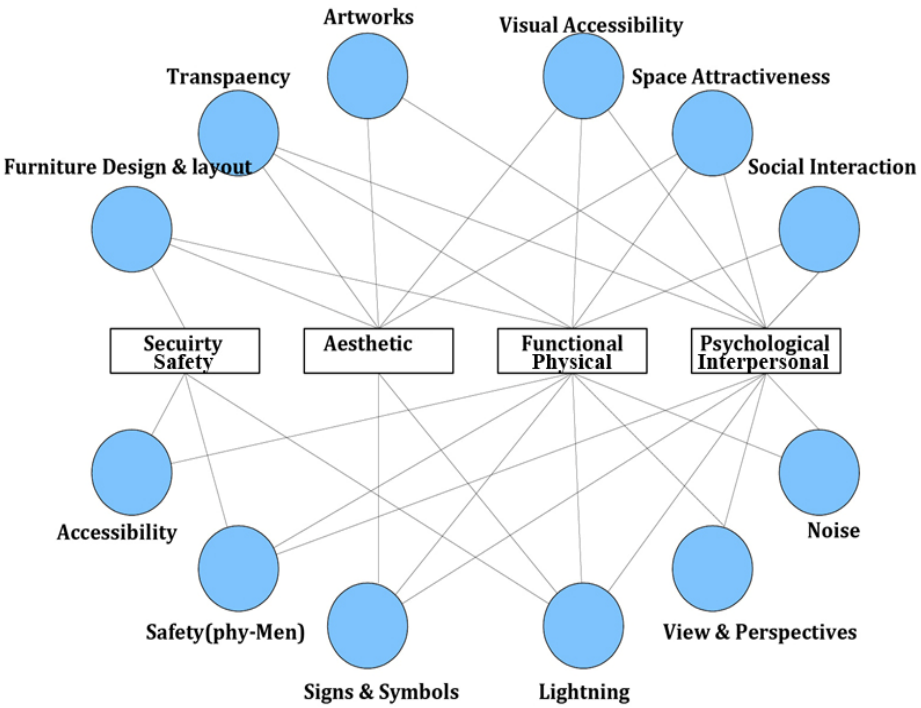

Fig. 7 Interrelationship between architectural factors which affect social interaction in subway stations.

5. Discussions

This study informed the evidences which introduce the effects of architectural factors toward more humanistic and social spaces which not only improve the social interaction between users, but also are in better relationship with human beings. Subway station is one of the examples of public spaces as these types of buildings are in close relationship with the social life of people. Therefore, consideration of space qualities in such public buildings is important.

In Tehran subway stations, some of these qualities have been neglected. This study addressed important factors that can improve the users' satisfaction regarding the relationship between people and environment.

6. Conclusions

The findings of this study indicated that several architectural factors contribute with improving social interactions in Tehran subway stations: accessibility and safety/security are the most important architectural factors in this regard. Furthermore, lighting, visual accessibility, signs and symbols, transparency and space attractiveness are the other factors which affect the social interaction in Tehran subway station as well. Therefore, in order to improve the social interaction in subway stations and creating more humanistic spaces it is recommended to:

- avoiding long, slim corridors and facilitating better accessibility from the entrance to the trains;
- using non-slippery surfaces in order to prevent injuries and provide more safety for the people who are in a rush;
- security/safety considerations in the stations, especially around the platforms which are not equipped with screen doors;
- providing day lighting especially in underground stations;
- providing enough visual accessibility which promote the sense of place for the users and improve their mentally safety;
- placing appropriate signs and symbols in order to improve the spatial orientation in the station;
- providing seating appropriate furniture can improve the social interaction between people;
- locating pieces of artworks, nature mural, and transparency in spaces along with space attractiveness will be beneficial to provide a domestic and friendly space which facilitates the interactions among strangers.

Possible differences of architectural factors in different stations affect the perception and the judgment of the subjects which may limit the generalizability of the findings. Additionally, the amount of time for filling the questionnaire forms in the subway stations was limited which decreases the accuracy of the results. This study brought to light the architectural factors which contribute to more social spaces to fill out the gap of knowledge in subway station design, however, this study can just play a starting role in this area and further studies and investigations with the consideration of architectural factors, design intervention and human factors in specific stations are needed.

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Human Factors in the Analysis of the "Tram-Car Drivers" at Intersections

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Abstract: The modern tramway has resurfaced as the cure to today's urban transport problems such as pollution, road congestion and uneven access to transit. However, trams at intersections often experience frequent and extended delays due to vehicles crossing the tram tracks. There is an increased potential for conflict between trams and vehicles at these locations and crashes are common. The question of the effects of human factors on trams crossroads safety has been little dealt with in literature. The general aim of this article is to further knowledge about the influence of tramway and surrounding environment on car's driver behavior at intersections. Understanding these influences, involve conducting a systematic review of the cognitive tasks related to driving and identifying the hazards that can arise at each task, and what factors can make these more or less likely to arise, considering the environmental design at intersections and behavioral factors. To achieve that, the HAZOP (Hazard and Operability Study) approach is conducted for this study. Concerning data collection, the methodology includes site visits to record user behavior and questionnaires to determine the opinion, concerns and knowledge of car drivers in interaction with the tram environment.

Key words: Tramways, intersections, human factors, road safety, cognition.

1. Introduction

In response to growing problems of road safety related to travel, the road transport network in Morocco has been modernized with the implementation of Rabat-Sale tramway since April 2011. The Moroccan government carried out this project to connect Rabat and Sale, twin cities located on either side of the mouth of the Bouregreg River. After Rabat, the city of Casablanca also launched the realization of this Tram project, whose railway length is almost 30 km. Even though the achievements are few, projects are there and therefore it is logical that Morocco is particularly concerned with the road security strengthening.

For further discussion some consensus about terminology seems to be useful. For the purposes of this paper, a tram system, tramway or tram is a railway on which streetcars or trolleys run. It is typically built at street level, sharing roads with traffic, but may include private rights of way especially in newer light rail systems [1].

The modern term "Light Rail" embraces tramways but goes further and faster than traditional tramways. However, there is no definite border line between "tram" and "light rail"—they merge gradually from one to another, and as a tramway system gets upgraded it becomes light rail.

In Morocco, road users are not qualified enough to adapt to the current situation of modern and advanced developments in the road traffic system. In fact, a study [2] conducted in Morocco in urban areas has shown that in comparison with the multitude of dysfunctions observed the accidents are few. In this report, the road traffic is distinguished by the local customs of behavior acquired over time with the evolution of the complexity of traffic. This finding justifies that research should be conducted to further knowledge about the influence of tramway and surrounding environment, (specifically at crossroads)

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on car' drivers behavior, and it is the general aim of this article. Understanding these influences, involve conducting a systematic review of the cognitive tasks related to driving and identifying the hazards that can arise at each task, considering the environmental design and behavioral factors.

The first part of the article seeks to investigate the interaction between trams and cars within the road network, the authors also discuss problems that drivers have to face with at crossroads. Then from a literature review of driver behavior psychological models, the authors propose their framework to study the interaction tram-car driver. In the third part, the hypothesis and research approach will be presented. The conclusion insists on the interest of this approach to understand the drivers' behavior and the interface between tram environment and car driver.

2. Car-Tram Interactions within the Road Network

2.1 Some Broad Issues

Cars and trams are at opposite in terms of size, mass and speed but they share the same road network. Both trams and cars may have parts of a roadway set aside for their specific use. However, specific issues of visibility and manoeuvrability are likely to occur at intersections. The interaction between cars and trams on the road system will have three major types of consequence on:

- Infrastructure capacity requirements: in terms of damages to the infrastructure and rolling stock that can occur during an accident and which may be heavy in terms of economic damages and number of victims. Indeed as a mode of public transport, the accidents involving tram with other road users may involve a large number of victims. However, as of now there is comparatively little information about the background of the involvement of trams in crashes in Moroccan urban areas, but the media side on accidents involving public transport (in this case a tram) should be noted, even though they are few, they are totally unacceptable to the public opinion;
- Operational performance, in terms of safety and travel time: conflicts between cars and tramway can have negative impacts on both trams and cars in different ways, causing tram delays and inconvenience;
- Perceptions, particularly by the car driver, which lead to changes in travel behaviour.

2.2 The Effects of the Tramway on Urban Transport

In all countries, the fight against pollution and congestion has been tackled in urban areas through the promotion of tramway as they have been considered the optimal option for fostering public transport patronage and also for getting a sustainable mobility for the growing urban population [3]. Tramways provide fast, regular, safe and comfortable services. At the same time, they provide a modern image of the city.

In spite of the growth in the interest of this urban rail system, it is well known that the tramway line implementation leads to changes, both in terms of the urban shape as on the overall functioning of the city. Indeed, the place occupied by the tram on the roadway is directly taken from the car. More specifically, most tram-car interaction within the road network takes place in the context of existing road infrastructure, which has physical limitations and implicit, sometimes explicit, limitations on additional capacity provision. But beyond the physical dimension of this competition for space, there is also a misunderstanding of the rules relating to this mode as of its constraints of traffic. The rule "tram has priority over all users" is explained by the fact that the tram is a vehicle on rails, it cannot avoid an obstacle but it is also explained by the big braking distance necessary to a tram to stop. More generally, tram priority is assuring the tram movement through an area without the potential detriment of others users of this area. These will often be where traffic volumes are high, traffic speeds are low and vehicles movements are

complex (e.g., intersections).

2.3 Crossroads Problem: Understanding Human Behavior

Crossroads navigation is a particularly hazardous component of driving. Even though crossroads comprise just a small amount of the roadway surface area, they generally are more complex and difficult to navigate than most other road segments. More specifically, crossroads can be visually complex, requiring that drivers scan several different areas and keep track of tram and several different elements to get the information they need to safely pass [4].

Specific issues of visibility and manoeuvrability are likely to occur at crossroads. So great attention is paid nowadays to the meaning of the space the driver is moving in. This area of research and action is known as the "road readability".

"Road legibility", "road readability" and "self-explaining roads" all raise the question of how the road infrastructure could support drivers' activity. The concept of the "self-explaining road" is defined in terms of the processes by which drivers' expectations are structured. "Self-explaining roads" are roads with a design that evokes correct expectations from road users (…). This means that drivers are given direct information about the type of road they are driving along and the type of behavior required [5]. Therefore, for a safe situation it is important that every road user can see all the other road users and that everyone knows what is expected of him.

In practice, however, the actual safety and convenience of road use depend heavily on driver's perceptions of both the road and traffic conditions and of other users.

In Morocco, traditional methodologies mostly focus on single effects of causing parameters to traffic unsafe situations. For example, in most of the statistical reports on traffic safety in Morocco [2], it is written "speeding behaviour has the highest percentage in all causes of traffic conflicts and/or accidents". However, to explain the accident, one should not seek to blame a single and last element, but to see how the interaction system broke down. Many researchers have considered that the problem is not unsafe drivers or unsafe road users, but the unsafe complex system. Drivers, pedestrians and other road users will continue to make errors as long as the road system exists. It was concluded [6] that rather than focusing entirely upon removing road user error, effective error management in road transport should focus on increasing the capacity of the road transport system to tolerate error. This fact has guided our research in this area to an approach that takes into account the Moroccan road context and behaviour of the driver in this context.

3. State of Knowledge on Human Behavior in Driving

3.1 Human Functional Failure

The specific role of human factors inside the traffic system has to be stressed in order to go further than the usual view on accidents factors. It is important to be aware of the very specific role of the human element: It is both a component and the principal actor [6].

When a driver fails to avoid an accident because the situation exceeds their limitations, it is often called "human error". Safe and efficient driving requires the adequate functioning of a range of abilities including vision, perception, cognitive functioning and physical abilities, and loss of efficiency in any of these functions can reduce performance and increase risk on the road [7].

It is consequently the same processes which allow the drivers to adapt to the difficulties of the environment and which sometimes may fail and lead them to the error. As the costs of human error can be very high, it is important to find out why human error happened and how it can be prevented in the future [8]. For this purpose, the cognitive approach is especially suitable for analyzing higher order functions such as problem solving and decision making.

3.2 Human Behavior Models

There is a great wealth of literature dealing with analysis models, giving preference in one way or another to the description of functional sequences such as: information acquisition, processing, decision and action. This type of model is aimed at understanding the malfunctions. Other model types are built up using the description of driving task [9].

Two theoretical models that originate from cognitive psychology and are frequently mentioned in the literature on road user behaviour are Endsley's model of information processing, and the hierarchical structure of the driving task as described by Michon. The reason for mentioning these models and not others, is that the models listed are all considered to be relevant for describing traffic behavior [10-12], and, more importantly, because they are complementary.

Endsley's model of information processing [13], serves as a starting point. Endsley proposes a model of human decision-making related to SA (situation awareness). The concept of situation awareness focuses on the mental picture of the situation that people find themselves in and how this picture can be distorted or improved by internal and external factors. Endsley's model illustrates three stages or steps of SA: perception, comprehension and projection.

The first level of SA, involves the processes of perception, cue detection and simple recognition, which lead to an awareness of multiple situational elements (objects, events, people, systems, environmental factors) and their current states (locations, conditions, modes, actions). At the second level of SA people combine, interpret, store and retain the collected information. The third and highest level of SA (called projection) involves the ability to project the future actions of the elements in the environment. These characteristics make it a suitable model for studying the formal stages involved in unsafe or undesirable situations.

We also borrowed from Michon [14] the distinction he makes in the driving task between the strategic, tactic and operational level. On the strategical level, driver makes decisions related to planning and executing a trip from origin to destination. The task on the tactical level requires taking decisions about driving speed and how to handle specific traffic situations such as crossing a crossroad. In this situational context, he plans manoeuvres that suit the navigational objectives. Finally, at the operational level, the driver takes decisions that relate to vehicle control [15].

It is obvious that other aspects of driver behaviour, such as experience, intentions, attitudes, emotions and spatial properties including location, size, separation, connection, shape, landmarks, and movement also play an important role in modelling driver behavior. Consequently, it is vital to be aware of how spatial knowledge and beliefs are acquired and developed over time, and how aspects of spatial knowledge and reasoning are similar or different among individuals or groups. This approach gained insight from the work of Lynch [16], a planner who argued that "images" of cities guide people's behaviour and experiences of those cities [17-19]. In fact, there is a growing need to include spatial cognition explicitly in models [20].

With this in mind, the articulation of models presented before seemed to authors particularly interesting to fully understand human behaviour in typical driving situations. The authors also combine notions of cognitive mapping to their analysis to suggest how cognitive mapping might be employed to help us better understand and predict driver behaviour. The authors therefore set out to develop a driver behaviour framework to generate and test hypotheses about the specific causes of unsafe driving behaviour in crossing crossroads that pass through tramway line. Fig. 1 shows the interaction and indicates variables moderating the hypothesized relationship to be tested in the field study.

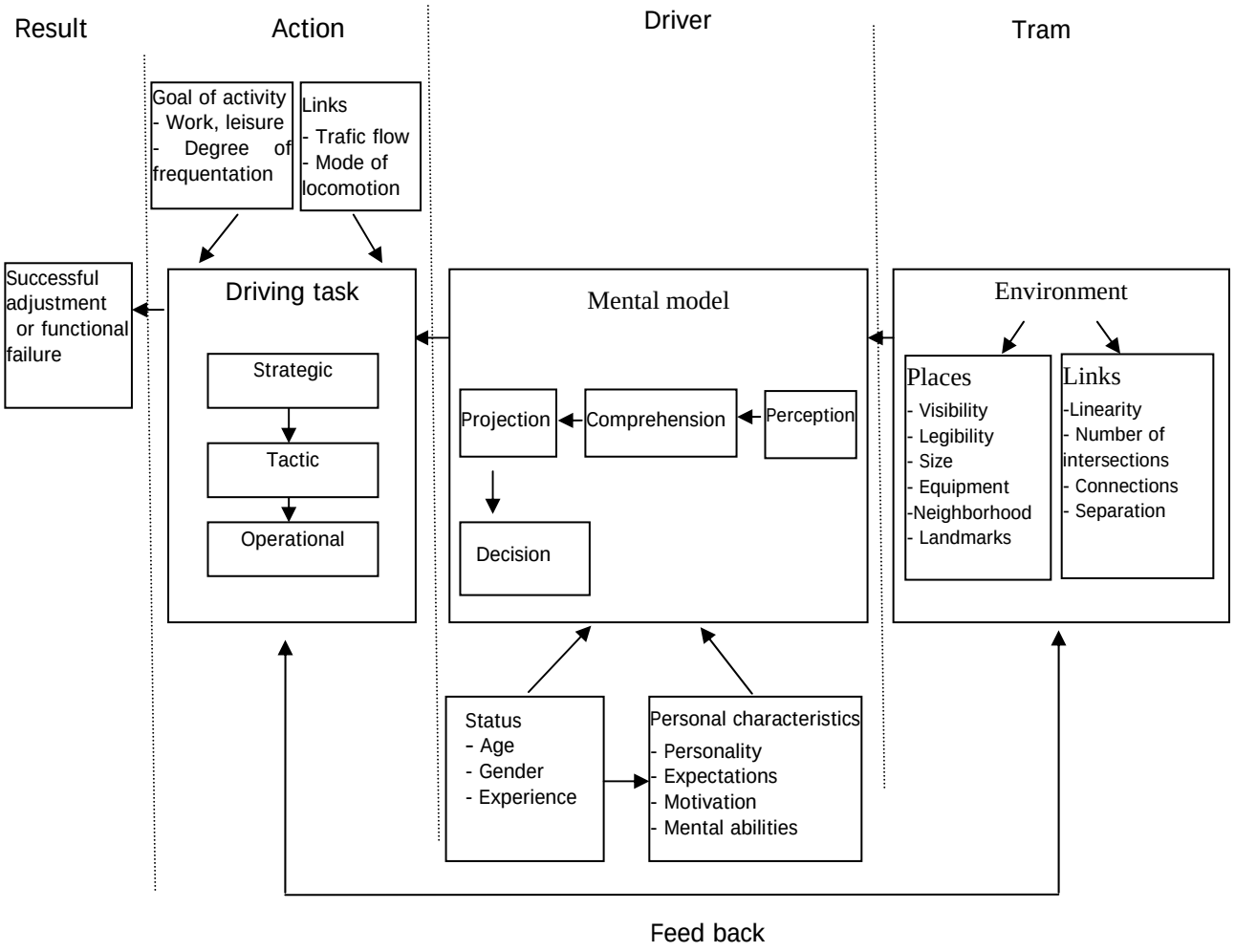

Fig. 1 Diagram for the tram-car driver interaction asses ment

4. Hypothesis and Research Method

4.1 Research Hypothesis

Several research work [21-23] have helped to affirm that road design elements play a role in the driving circumstance difficulties. These different studies have led the authors to formulate the general hypothesis of research, which can be defined as follows: Driver behaviour at tram crossroads will depend very much on what is seen or "not seen" by the driver, in the road scene and how he "reads" the situation.

Briefly speaking, our analysis aims to answer three questions:

(1) How (how often) do people behave at specific crossroads crossed by tramway line;

(2) Why do they behave that way;

(3) What are the results of such different behaviours.

4.2 Research Methodology

To meet the research hypotheses, the methodological proposal is largely based on the functional and dysfunctional approaches which are consistent with the goals of this study. Among them are such techniques as HAZOP. In the study, failure constitutes the limits of cognitive functions engaged by the driver in a context of driving activity at crossroad. For each failure that refers to a function of the driver's mental model in degraded mode, a quantitative and qualitative assessment will be

conducted to identify potential accidents that can result from the deviations, to determine the cause of the deviation and to find the safeguard which helps to reduce frequency of problems encountered by drivers in crossing tram crossroad.

HAZOP is a classic tool of the industrial world, the authors tried to adapt it to the context of the study by simplifying it to facilitate its ownership by stakeholders. At this level, their work joins several studies HAZOP in the road sector including one conducted by a research program initiated by "Rail safety standards and Board" and whose results were published in the report "Understanding Human Factors and Developing" risk reduction solutions for pedestrian crossing at railway stations [24].

To validate the hypotheses and the methodological proposal, a particular attention is paid to the data collection. Observational surveys will be used to record user behaviour and a questionnaire to determine the opinions, concerns and knowledge of users. The observation is based on an analysis grid to carry out the assessment, and to examine whether it would be possible to identify characteristics of crossroads that coincide with a higher likelihood of unwanted events. To guide the choice of elements to be included in this grid, the authors were inspired by the work of Millot [21] taking care to adapt the reading points to the field of study and to their specific questions. To complement those observations, a face to face interview using the existing situational questions, will be conducted to encourage drivers to express their opinion and share their experiences which will contribute significantly to gathering information for hazard identification and prevention of traffics accidents and congestion.

4.3 Validation

As a first step, a validation exercise was carried out to assess the feasibility of the methodology. Two crossroads at Rabat city were selected according to the number of collision and related incidents that occurred there in the last year 2012.

During the validation exercise, observations were carried out. This involved spending periods of time at each crossroads and observing the behavior of users. A review of the physical aspects of each crossroad and its surrounding were made. An assessment of the driver's behavior during a journey within the vehicle itself was also used. At varying intervals during the crossing, the participants were asked relevant questions about the scene in order to determine their knowledge and their representations of the driving situations studied, in addition to this a detailed explanation of the driving process was provided by the drivers as they progressed through the sequence of each roundabout, this technique allows previously unknown parameters to be found and enables driver to make comments about his behavior, especially as regards to the environmental conditions which influenced him and came into play in the various situations he encountered.

4.4 Preliminary Findings

The following list highlights a number of human factors and design features at each crossroads that can have an influential role in unwanted events and contribute to unsafe conditions. The list can be supplemented by further observations and interviews:

(1) At crossroad united nation street at Rabat

• A high traffic volumes and pedestrians movement due to shops, this requires car drivers to be alert for pedestrians and tram approaching;

• A stop line is not demarcated, either with a white line or appropriate pavement marking, to help drivers identify safe stopping location;

• Tramway signs are not always conspicuous due to their position relative to other signs;

• Parked cars before and after the tramway line may result in vehicle drivers slowing and being caught on the tracks while a tram approaches;

• Non compliance with traffic signal encouraged sometimes by police due to problems of traffic

congestion;

• The sequence of lights is believed to be confusing to car drivers;

• The crossing being completed without the necessary caution increases during rush hours and on working days.

(2) At crossroad street IBN ROCHD

• At some locations there is considerable visual clutter from surrounding infrastructure, which can detract from the primary safety messages "give way to tramway" and "beware of tram";

• Text in association with trams signs can be hard to read due to car driver's speed;

• Some users failed to fully understand the meaning for various trams signs and are not aware of the rules and procedures for correctly using trams crossroads;

• Drivers can be distracted from scanning for trams while they seek an appropriate gap in traffic on main road;

• A stop line is not demarcated, either with a white line or appropriate pavement marking to help drivers identify safe stopping location;

• Vehicles waiting or queuing across the tram tracks due to traffic congestion;

• The curvature of the intersection creates a difficult angle from which to observe on-coming trams;

• The desire to pick gaps generated by traffic platoons can result in crossing being completed without the necessary caution, indeed the amount of time the users expect to wait at trams crossroads may influence their risk taking behavior.

5. Conclusions

There is very little literature concerning the interaction between tram environment and the drivers' behaviour. To address this issue we are therefore oriented towards the methods used in urban development, and human cognition.

While moving, the driver evolves—particularly in crossroads—in a complex and extremely dynamic environment, hence the need to set up developments which allow the driver to discern, to identify and to choose easily in this environment, the indices for the effective regulation of its activity.

The methodology the authors have presented here represent an analytical approach. The interest of this approach is that it attempts to obtain an overview of drivers' behaviours in specific driving situation (e.g., crossroad crossed by tramway line) and the variables likely to explain them using complementary indicators: site visits to record user behaviour and questionnaires to make drivers precisely explain their perceptions of the facts, their decisions, actions and the difficulties they encountered.

The conclusions of the preliminary findings of the study has identified a number of problems associated with tramway crossroad and has explored some of the road design and human factors that contribute to the difficulties experienced by drivers at these intersections. It is clear that much further investigation is required on the causal factors of errors and on the implications that these driver errors have on tram crossroad safety. The second stage of the study is now to address the relationship between the elements of the tram environment and types of driver errors, this work is on progress, with the aim to provide suggestions for minimizing potential conflict between cars and trams and for enhancing error tolerance at crossroads that pass through tramway line and within the Moroccan road transport system in general.

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A Comparison of Different Approaches in Numerical Modeling of Pavement Granular Material

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Abstract: Modeling pavement granular materials have played a significant role in pavement design procedure. Modeling can be through an experimental or numerical approach to predict the granular behavior during cyclic loading. Current design process in western Australia is based on linear elastic analysis of layers. The analysis is largely performed through a well-known program CIRCLY which is applied to model bound pavement material behavior. The KENLAYER is one of the common pavement software models used for pavement design in the United State which performs non-linear analysis for granular materials. Alternatively, a general finite element program such as ABAQUS can be used to model the complicated behavior of multilayer granular materials. This study is to compare results of numerical modeling with these three programs on a sample constructed pavement model. Moreover, a parametric study on the effects of Poisson ratio over the surface deflection of the flexible pavement has been conducted. It is found that increase in Poisson ratio of asphalt layer will increase the surface deflection while the increase in Poisson ratio of granular layers decreases the surface deflection.

Key words: Flexible pavement, numerical analysis, ABAQUS, CIRCLY, KENLAYER.

1. Introduction

Design and construction procedures for transportation infrastructure such as road pavements, railway formations, and airfield pavements are aimed at assessing the permanent deformations and fatigue cracking of the bound or unbound layers. Currently, there is a growing trend to use computer software in design and analysis of pavement materials, however, each of these programs has its own specific ability and limitations. These computer programs are manipulated to model (called numerical modeling) behavior of flexible pavement under certain condition. Two different approaches are usual: first approach is using an analytical solution provided from theory of elasticity with calibration factors to match empirically observed behavior while second approach is implementation of finite element technique to solve general equilibrium of the whole layered system.

The advantages of numerical models for designers and researches are that they are considerably cheaper and they provide very rapid computation on standard computers. Moreover, in numerical modeling the full layered pavement system behavior can be observed and investigated.

1.1 Review of Elastic Computer Programs: CIRCLY 5.0 and KENLAYER

Based on linear elastic theory, an analytical solution of layered semi-infinite half-space can be calculated. The assumptions are that stress-strain behavior is linear elastic and the pavement domain has no limit in horizontal direction. In vertical direction, there is a horizontal stress-free surface at top of the medium while the bottom is extended to infinite depth.

Two well-accepted pavement design programs, KENLAYER and CIRCLY, calculate pavement system responses (stress, strain, deformation, etc.) based on elastic theory.

The KENLAYER Computer Program (Huang [1, 2]) is accepted computer program which can model pavement layers as linear elastic, nonlinear elastic or as

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Mohr-Coulomb elastoplastic materials. The main core of KENLAYER is the solution for an elastic multilayer system under a circular loaded area.

The KENLAYER Computer Program can only be used to analyze flexible pavements with no joints. This program can use the superposition principle for multiple wheels. It can also use an iterative technique to solve non-linear problems [3].

Gedafa [3] used KENLAYER and HDM-4 to analyze flexible pavement performance. In this study, these two computer programs have been compared. It is concluded that KENLAYER is can be more easily applied to performance analysis while HDM-4 is a more powerful tool in the field of strategy analysis.

CIRCLY [4] is a computer program for pavement design and can be applied to material analysis. It can model materials either isotropic or anisotropic. The load is considered as the tyre pressure uniformly distributed over a circular area. The analysis is assumed to be under static condition and superposition principle is valid.

CIRCLY was developed as a geomechanical program in the Division of Applied Geomechanics of CSIRO (Commonwealth Scientific and Industrial Research Organization) of Australia. Then in 1987, the NAASRA (National Association of Australian State Road Authorities) used CRICLY in the Guide to Structural Design of Pavements. This is the basis for "Guide to Structural Design of Pavements" developed and modified by AUSTROADS (formerly NAASRA) in 1992 and 2004. The CIRCLY 5.0 (current version of the program) is written in FORTRAN IV [5].

One of the referred studies in which an interesting comparison has been presented was undertaken by Ullidtz [6]. In this paper, six pavement program including CIRCLY and KENLAYER were compared against the measured field data. Field data is collected from three full scale pavement projects from CEDEX (Centro De Estudios Y Experimentacion De Obras Publicas) in Spain, DTU (Technical University of Denmark) in Denmark and LAVOC (Laboratoire Des Voies De Circulation) in Switzerland.

A review of the mechanistic design approach in pavement design has been undertaken by Wardle et al. [7]. According to Wardle, "unbound layers should be 'sub-layered' in order to better model their non-linear response. If a non-layered model is used, the computed strains caused by a vehicle will be different, and the failure criterion that is then derived from performance data using the different strains will also be different." In this study, CIRCLY is manipulated to calculate the vertical strain for 4 t and 20 t wheel load and the results is plotted in different depth.

Hadi and Symons [8] have compared results of the CIRCLY program with a finite element model constructed in MSC/NASTRAN and STRAND. According to their study, CIRCLY resulted in a lower number of allowable repetitions based on AUSTROADS recommended loading.

Tutumluer et al. [9] compared the results of pavement modeling through finite element program GT-PAVE and CIRCLY for a cross anisotropic model. In this study, the two programs were used to calculate the elastic response of layered pavement system. Although both of these programs are based on an analytical solution, they are unable to produce "the exact" results. The reason is that in both programs, the calculation approach is numerical and there is a level of approximation in each.

1.2 Review of ABAQUS Application in Flexible Pavement Modeling

Advancing technology in computers is making it more attractive for engineers to use advanced computational methods instead of analytical solutions limited by computer power. One of the most accepted methods among the available options is the FEM (finite element method). The main advantage of FEM-based programs is their ability to model various types of mechanical loadings and behaviors in a two or three dimensional medium.

Recently the ABAQUS program, a general purpose

FEM program, has been employed to model layered flexible pavement system.

Zaghloul and White [10] have used ABAQUS to model the three dimensional behavior of a pavement layered system under dynamic loading.

Mallela and George [11], Uddin et al. [12] and Cho et al. [13] also employed ABAQUS in a three dimensional model. Kim et al. [14-16] have used the general purpose finite element computer program ABAQUS in their study on modeling the nonlinear behavior of the stress-dependent pavement foundation (subgrade).

Vuong [17] has investigated the effect of repeated loading on pavement granular materials. In this study, a nonlinear finite element has been used to predict the stress-strain response of the pavement system. Many loading conditions, including single, tandem, tri and quad axle have been chosen to validate the finite element analysis results.

Bodhinayake [5] has used the ABAQUS to model nonlinearity in subgrade soil while other pavement layers has been modeled as a linear elastic material.

In the current study, the ABAQUS software package is used to determine its capacity and compare the output with the KENLAYER and CIRCLY programs.

1.3 Current Study

The main purpose of this research is to compare three different programs which use different approaches to predict the behavior of pavement materials. To do so, three well-known programs which are: KENLAYER, CIRCLY and ABAQUS are manipulated to construct a sample layered pavement system. A fixed geometry and load condition is chosen for analysis. The analysis has been repeated whilst varying Poisson ratio individually to the asphalt layer, granular layer and subgrade to determine the sensitivity to this parameter, the results of analysis from each program have been extracted and compared.

2. Numerical Modeling

While there is a traditional inclination towards laboratory and field tests in pavement engineering, recently the numerical modeling option has attracted many researchers. Duncan et al. [18] first used the finite element approach in flexible pavements analysis. Huang [19] calculated stresses and displacements in nonlinear soil through finite element modeling. Since then many authors have used numerical modeling to calculate induced damage in pavement layers, including the asphalt layer, base and subgrade.

In the first step of this study, a sample layered pavement system has been modeled in CIRCLY, KENLAYER and ABAQUS. The result of surface deflection is then plotted and compared. In the next step, different Poisson ratios for each layer have been modeled and the results of the three programs are presented.

2.1 Characteristics of the Model

A sample section of a layered pavement with same thickness, geometry and loading characteristics is modeled in the aforementioned programs. Fig. 1 illustrates the geometry of the modeled pavement.

The material properties of the first trial run are listed in Table 1. All layers are assumed to behave linear elastically under a 0.75 MPa pressure loading, which is applied over a circular area of 92 mm radius. This is taken as a circular representation of the tyre pressure in the AUSTROADS method employed in CIRCLY (AUSTROADS [20]).

Materials properties for the first analysis are presented in Table 1.

2.2 Constructed Model in KENLAYER and CIRCLY

KENLAYER and CIRCLY are based on elastic theory. In three-dimensional elastic analysis, the stresses and strains are related to each other. Eq. (1) shows this relation [21]:

$$\begin{aligned} \varepsilon_{xx} &= \frac{1}{E}\left[\sigma_{xx} - \nu\left(\sigma_{yy} + \sigma_{zz}\right)\right] \\ \varepsilon_{yy} &= \frac{1}{E}\left[\sigma_{yy} - \nu(\sigma_{xx} + \sigma_{zz})\right] \\ \varepsilon_{zz} &= \frac{1}{E}\left[\sigma_{zz} - \nu\left(\sigma_{xx} + \sigma_{yy}\right)\right] \end{aligned} \quad (1)$$

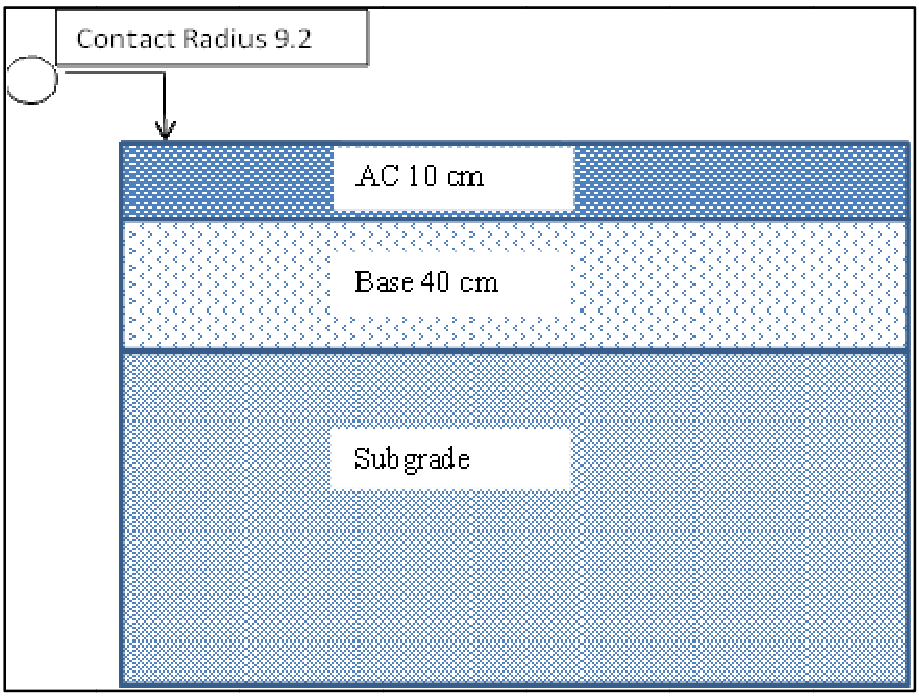

Fig. 1 Constructed model in KENLAYER and CIRCLY.

Table 1 Material properties for KENLAYER and CIRCLY programs.

Layer	Thickness (mm)	Elastic modulus (MPa)	Poisson ratio
Asphalt (AC)	100	2,800	0.4
Granular (Base/Subbase)	400	500	0.35
Subgrade	Infinite	62	0.4

where,

σ is the normal stress along the axes;

ε is the normal strain along the axes;

E is the elastic modulus of the materials;

v is the Poisson ratio.

However, in this study the models are constructed and analyzed in two dimensional axisymmetric conditions. When axisymmetric conditions are applied, the full three-dimensional equation can be reduced to Eq. (2):

$$\varepsilon_r = \frac{1}{E}(\sigma_r - \nu\sigma_z)$$
$$\varepsilon_z = \frac{1}{E}(\sigma_z - \nu\sigma_r) \quad (2)$$

where,

σ_r is the radial stress;

σ_z is the vertical stress;

ε_r is the radial strain;

ε_z is the vertical strain;

E is the elastic modulus of the materials;

v is the Poisson ratio.

Based on Eqs. (1) and (2), one of the two influencing material properties in elastic modeling is Poisson's ratio. Whilst the overall design is relatively insensitive to variations in Poisson's ratio, an investigation over its effect on the surface deflection is of value.

To investigate the effects of material properties on the analysis, the geometry in Fig. 1 is assumed to be consistent in different section of the analyses (while materials properties are to modified).

For layered pavement systems, multi-layer elastic theory is applied where the pavement system is considered as horizontally infinite layers. These layers are of determined thickness in the vertical direction. In pavement analysis, it is also usual to consider the last layer (subgrade) as a vertically infinite layer. Therefore, the whole system is modeled as multi-layered

semi-infinite half space. The other assumption applied in the elastic model used in CIRCLY and KENLAYER is a full friction condition between two consecutive layers. Finally, the surface of pavement system is considered as a frictionless layer causing no shear stress [5].

2.3 Finite Element Model

While CIRCLY and KENLAYER use an analytical equation for multi-layered half space medium to simulate the actual condition of pavement structure, the finite element approach tries to predict the mechanical response of the system through solving by equilibrium of forces. The assumption here is that the model should satisfy continuity of medium (no crack is modeled).

Although this method of modeling is more difficult, it has the advantage to model various types of loading conditions, geometry and material behavior. This capacity is implemented in ABAQUS program very effectively.

Fig. 2 illustrates the geometry of FEM model. The material properties are the same as listed in Table 1. However, the geometry of the model in ABAQUS cannot be the same as CIRCLY and KENLAYER because the horizontal and vertical dimension must be finite. To overcome this problem Duncan et al. [18] suggested a dimension of 50-times *R* (loading radius) in vertical and 12-times *R* in horizontal direction. Kim et al. [16] found a good agreement between results of the FE analysis and KENLAYER when the model dimension is 140-times *R* in vertical and 20-times *R* in horizontal direction. In this study, after several trial runs, the final dimension of model has been selected as 55.35 times *R* in horizontal direction and 108.70 times *R* in vertical direction.

Fig. 3 shows the constructed FE meshes for the axisymmetric 2D analysis. Vertical lines on both sides of the finite element model are bounded with roller boundary condition which permits the displacement in the vertical direction but prohibits it in the horizontal direction. The base of the model is fixed in every direction. The model contains 3,402 biquadratic axisymmetric quadrilateral reduced integration elements and 10,453 nodes.

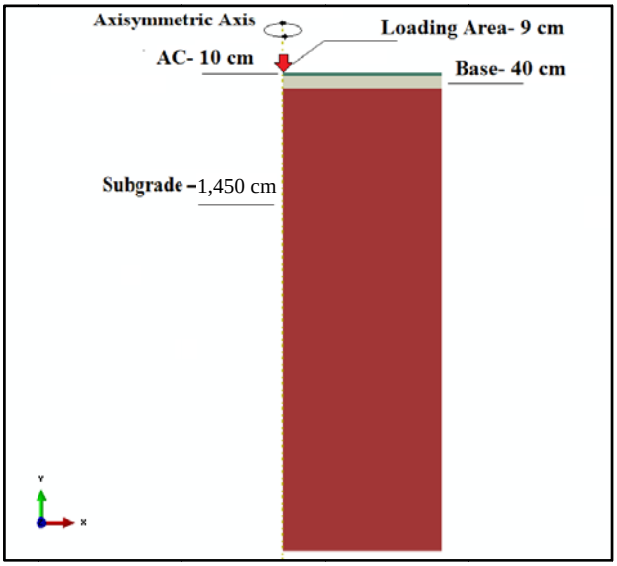

Fig. 2 Constructed model in ABAQUS.

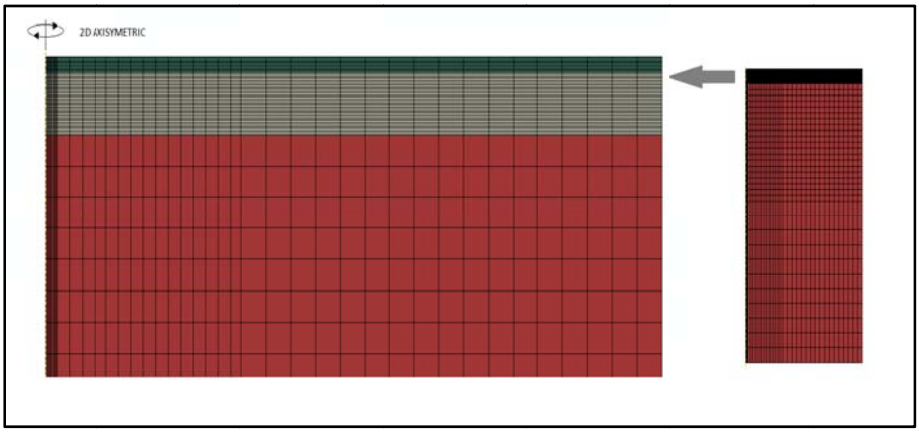

Fig. 3 Mesh properties of FEM.

The first step of the analysis is performed to verify the finite element model accuracy against the elastic solution models. The results of surface deflections calculated by each model are presented in Fig. 4. Whilst an acceptable agreement is observed, the surface deflection determined by ABAQUS is less than what is determined by KENLAYER and CIRCLY. It can be interpreted that the finite element mesh is behaving slightly "stiffer" than the analytical solution.

3. Effect of Poisson Ratio on the Numerical Results

The next step of this study was to determine the effect of variation in Poisson's ratio on the numerical prediction of surface deflection for the constructed model. This was achieved by applying six different Poisson ratios for each layer and determining the vertical displacement beneath the center of the tyre contact area. In each case where the Poisson's ratio of a selected layer is modified, the material properties for all other layers are maintained constant as presented in Table 1. For example, when the Poisson's ratio for asphalt layer is varying from 0.2 to 0.45, the Poisson ratio for the base and subgrade are assumed to be 0.35 and 0.4, respectively.

It is worth mentioning that the range of assumed Poisson ratios is beyond the accepted ranges, such as 0.2 for asphalt layer or 0.45 for granular base layer, but have been applied solely to investigate the trend in the behavior of the model and determine the sensitivity of the models to this parameter.

Figs. 5-7 illustrate the results of surface deflection for the variations in Poisson's ratios in each layer. For comparison purposes the results obtained from the three programs are presented conjointly.

Fig. 5 shows the effect of variations of Poisons ratio on the asphalt layer, and whilst the numerical magnitude of the calculation is different, the trend is the same for each model.

Fig. 6 shows the effect of variations of Poisons ratio on the base layer, and whilst the numerical magnitude of the calculation is different, the trend is the same for each model.

It can be seen that CIRCLY shows the largest values for the deflection in all cases, while the ABAQUS values are the lowest, and KENLAYER gives a result between these two.

However, the variation in the Poisson ratio for the base layer and asphalt layers leads to opposite trends in surface deflection. The increase of the Poisson ratio for

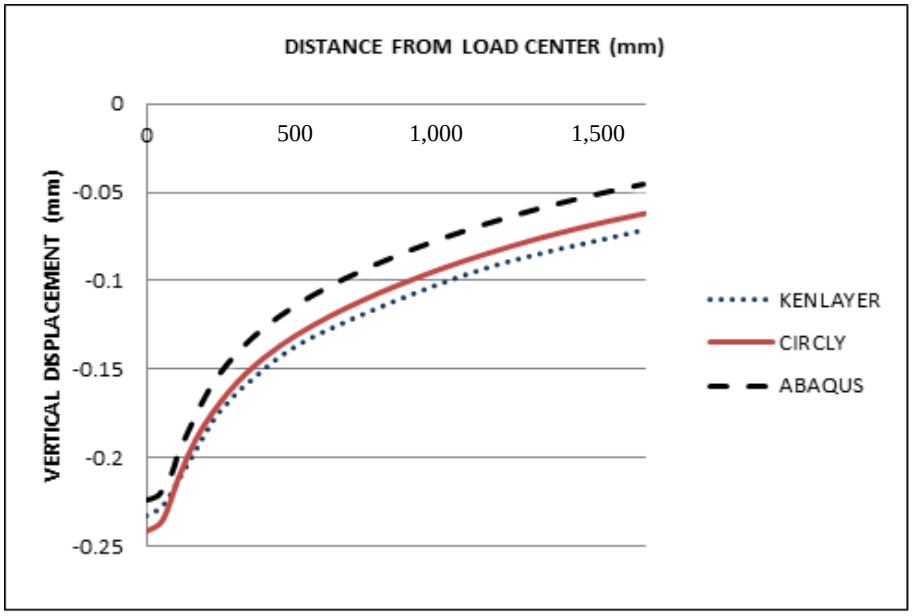

Fig. 4 Comparison of surface deflection.

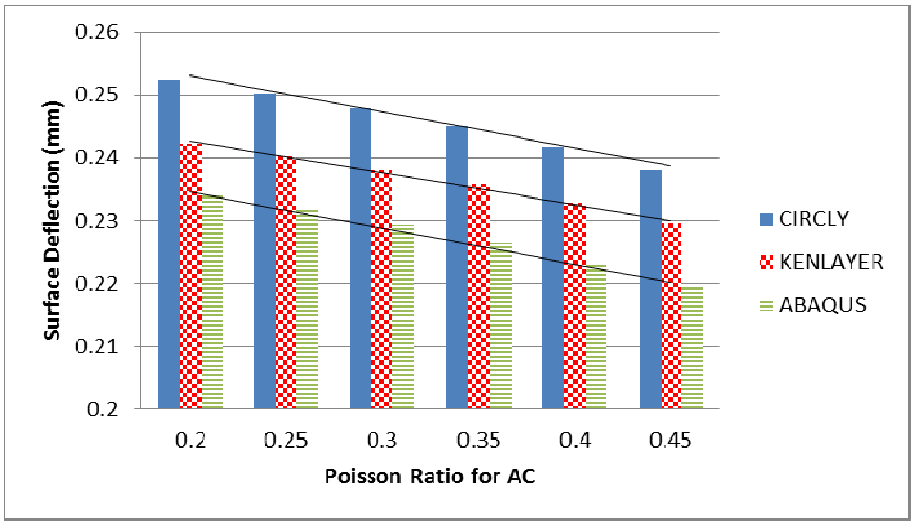

Fig. 5 Surface deflection vs. variation of Poisson ratio of the asphalt layer.

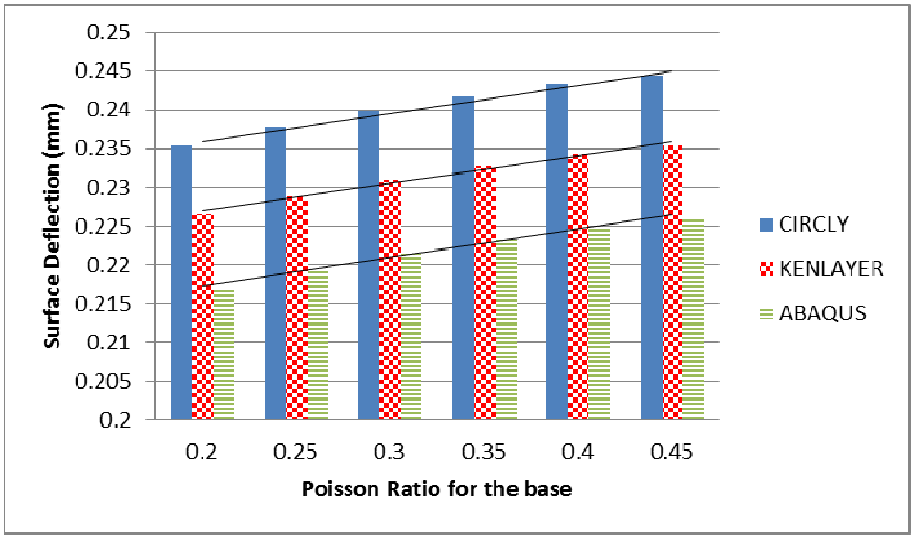

Fig. 6 Surface deflection vs. variation of Poisson ratio of the base layer.

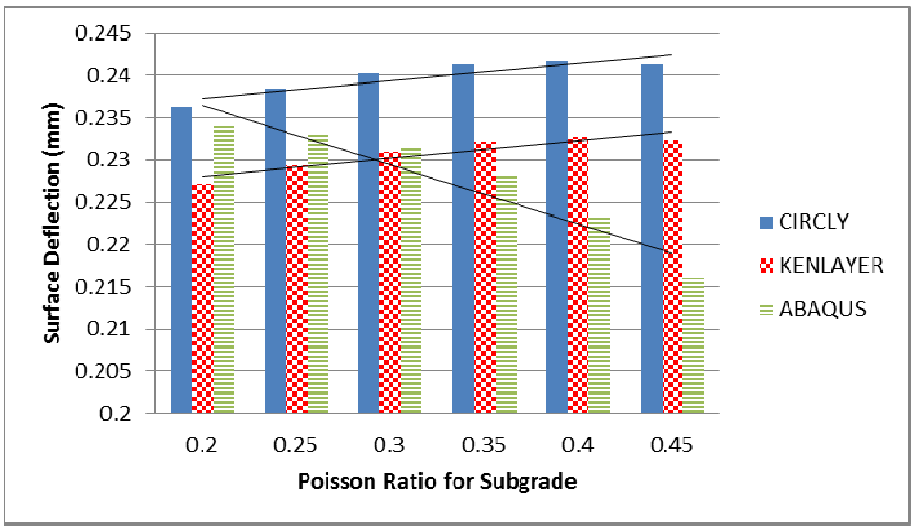

Fig. 7 Surface deflection vs. variation of Poisson ratio of the subgrade layer.

the granular base layer results in the increase of the surface deflection, where an increase in Poisson's ratio in the asphalt layer leads to a decrease in calculated deflection.

When Poisson's ratio for the subgrade layer is altered, unlike the case for asphalt and the base course layer, the three programs do not produce a common trend for deflection. As shown in Fig. 7, the calculated deflections from ABAQUS indicates decreasing deflection as Poisson's ratio is increased, where both CIRCLY and KENLAYER indicate the opposite trend. This is due to the effect of the boundary condition in FEM versus the analytical elastic solution. The finite element model requires finite boundaries in both vertical and horizontal directions and the assumption is made that a sufficiently large mesh size in the horizontal and vertical direction will behave as an infinite layer. However, the values predicted surface deflections from the FE model are in an acceptable agreement with the other two programs.

The maximum difference occurred when the subgrade Poisson's ratio was assigned a value of 0.45. CIRCLY determined the highest deflection at 0.241 mm and ABAQUS the lowest at 0.216 mm, an 11% difference. At a Poisson's ratio of 0.2, ABAQUS determined a deflection of 0.233 compared to a CIRCLY determination of 0.236. And at a Poisson's ratio of 0.3, KENLAYER and ABAQUS were in agreement.

The sensitivity of predicted surface deflections for the modeled pavement towards variation in Poisson's ratio in each layer is shown in Figs. 8-10. It is noted again that the Poisson's ratio of only one layer is varied in each trial run, with the other layers remaining constant.

The most sensitive layer to variations in Poisson's ratio in CIRCLY and KENLAYER is the asphalt layer. Fig. 8 shows the variation of surface deflection in CIRCLY where increasing Poisson ratio from 0.2 to 0.45 in the asphalt layer leads to decrease of surface deflection from 0.252 mm to 0.238 mm or 5.6%. In the case of Fig. 9 shows for KENLAYER the variation is from 0.242 mm to 0.229 mm or 5.3% for the same range.

Fig.10 shows the case for ABAQUS where the most sensitive layer is subgrade. Increasing the Poisson ratio of the subgrade from 0.2 to 0.45 resulted in decrease of surface deflection from 0.234 mm to 0.216 mm or 7.7%.

4. Conclusions

A sample of layered flexible pavement is modeled in

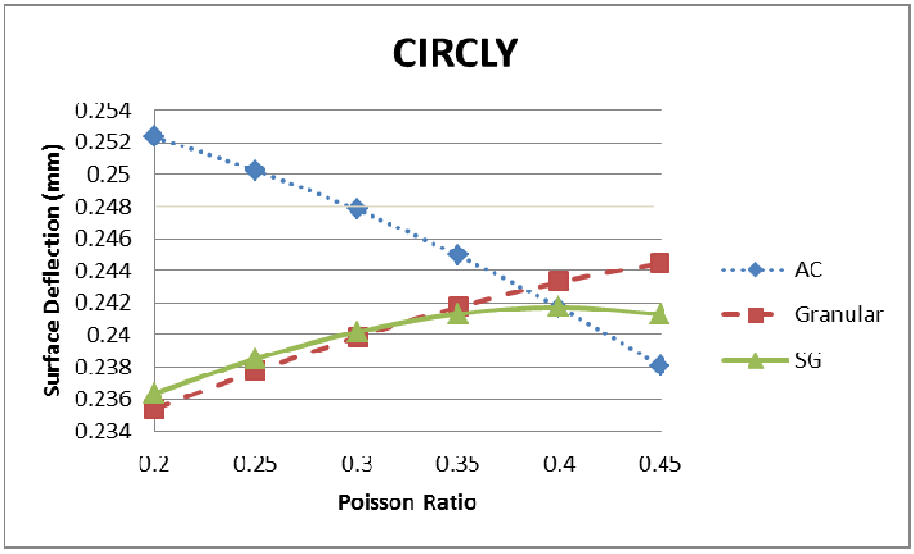

Fig. 8 Effect of the variation of Poisson ratio on the surface deflection calculated by CIRCLY.

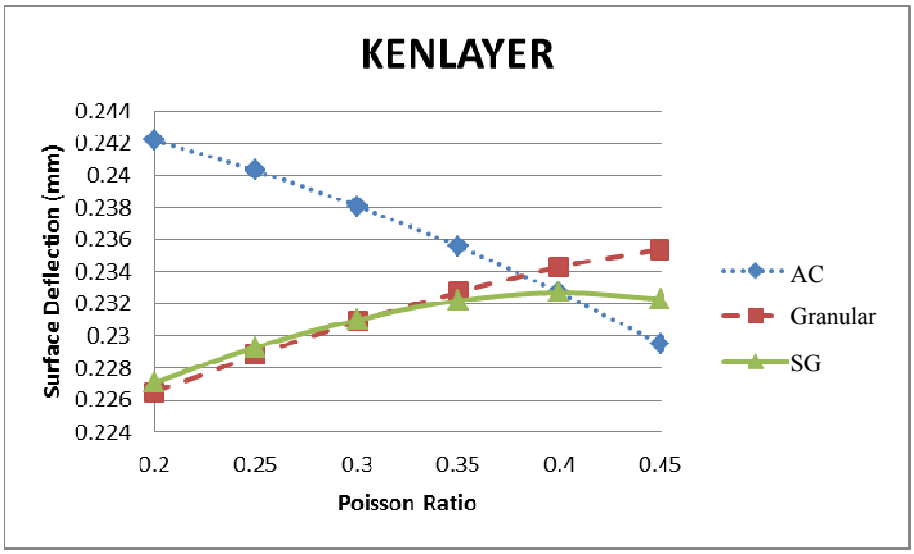

Fig. 9 Effect of the variation of Poisson ratio on the surface deflection calculated by KENLAYER.

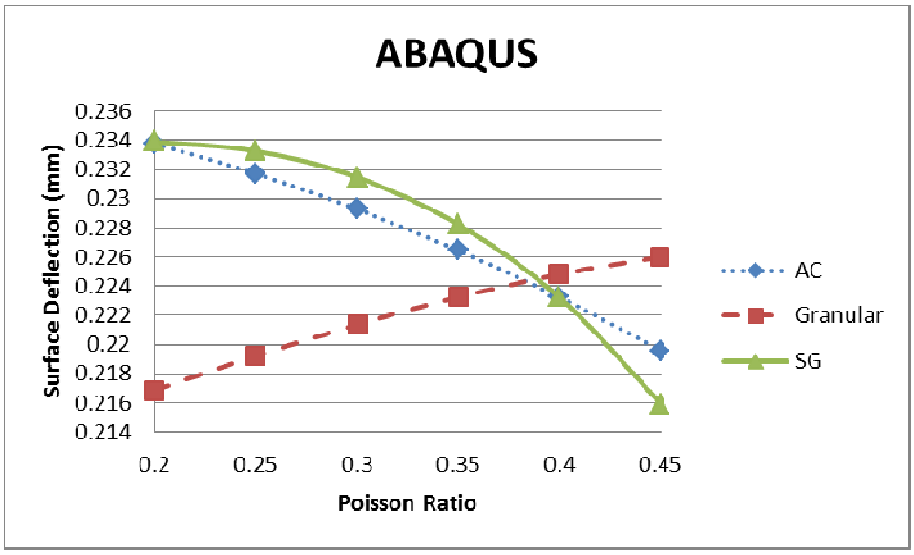

Fig. 10 Effect of the variation of Poisson ratio on the surface deflection calculated by ABAQUS.

three different programs that are CIRCLY, KENLAYER and ABAQUS. CIRCLY and KENLAYER are based on multilayer elastic theory while ABAQUS is a general purpose finite element programs. The Poisson ratio of the each layer was varied whilst the other two layers held constant, and the vertical displacement at the surface is compared in the three programs using the same loading conditions and material properties. While the general value of surface deflection are in acceptable agreement in all three programs there are dissimilarities in the predicted results and trends of responses. These differences can be attributed to the inbuilt assumptions and capabilities of each program.

The most fundamental difference is that both multilayer elastic programs model pavements of infinite horizontal dimensions, with an infinite depth subgrade, where the finite element model requires finite dimensions at all times.

The method of calculation which is used by KENLAYER and CIRCLY is different, they use different numerical integration technique that this can be the cause of different results.

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Investigation in Mathematical Models of Chloride Diffusion Coefficient in Concrete Exposed to Marine Environment

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Abstract: Degradation of RC (reinforced concrete) in maritime structures has become a worldwide problem due to its excessive costs of maintenance, repair and replacement in addition to its environmental impacts and safety issues. Degradation of both concrete and steel which is the main reason of reduction in the service life of RC structures strongly depends on the diffusion process of moisture and aggressive species. In this paper, the major and popular mathematical models of diffusion process in concrete are surveyed and investigated. Predominantly in these models, the coefficient of chloride diffusion into the concrete is assumed to be constant. Whereas, experimental records indicate that diffusion coefficient is a function of time. Subsequently, data analysis and comparisons between the existing analytical models for predicting the diffusion coefficient with the existing experimental database are carried out in this study. Clearly, these comparisons reveal that there are gaps between the existing mathematical models and previously recorded experimental results. Perhaps, these gaps may be interpreted as influence of the other affecting parameters on the diffusion coefficient such as temperature, aggregate size and relative humidity in addition to the water cement ratio. Accordingly, the existing mathematical models are not adequate enough to predict the diffusion coefficient precisely and further studies need to be performed.

Key words: Chloride diffusion coefficient, corrosion of steel in concrete, mathematical model of diffusion.

1. Introduction

Reinforced concrete has been used for construction of infrastructures around the globe due to its durability, good compressive strength and relatively lower cost. However, diffusion of aggressive ions such as chloride into the concrete can cause severe deterioration of structure due to corrosion of embedded steel reinforcing. Corrosion of reinforcing steel in concrete caused by chloride transport in concrete in marine environment has received increasing attention in recent years because of its widespread occurrence and high cost of maintenance and repair [1, 2]. Reinforced concrete structures are generally exposed to various environmental conditions during their lifetime. Therefore, degradation of materials and subsequently premature deterioration may occur which can significantly affect the service life of the structures [3].

According to the vast investigations, it is found out that the dominant factor of degradation process is the chloride-induced corrosion of the steel reinforcement in concrete [4, 5]

According to the recent intensive study commissioned by the United States FHWA (Federal Highway Administration), the annual direct cost of corrosion in the United States was 276 billion dollar in 1998, or 3.1% of the GDP (gross domestic product) [6]. Cost analyses of corrosion were also conducted in other countries, such as the United Kingdom, Japan, Australia and Kuwait. Even though the level of effort varies greatly among these studies, all of them have estimated the total annual cost of corrosion as ranging

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between 1% and 5% of each country's GNP (gross national product).

2. Mathematical Models of Diffusion

There are a few number of mechanisms such as diffusion, absorption, migration in an electrical field by which chloride transport can take place in concrete.

Diffusivity is the relationship between the concentration flux J of diffusing material and the gradient of the chemical potential that is assumed to drive the mass diffusion process. Most of the conducted studies on diffusion-based mathematical models are supported by Fick's law of diffusion. Fick's law relates the diffusive flux to the concentration field, by postulating that the flux goes from the regions of high concentration to the region of low concentration, with a magnitude that is proportional to the concentration gradient (spatial derivative) dimension.

Fick's second law can be expressed as follows:

$$\frac{\partial \phi}{\partial t} = D\frac{\partial^2 \phi}{\partial x^2} \tag{1}$$

where, ϕ is the concentration rate of diffusive flux (mol/m^3), t is the time (s), D is the diffusion coefficient (m^2/s) and x is the location (m).

If we assume that the diffusion coefficient is not constant and depends upon the coordinate and/or concentration ratio, Fick's second law can be defined as Eq. (2):

$$\frac{\partial \phi}{\partial t} = \nabla\left(D \cdot \nabla \phi\right) \tag{2}$$

Since the chloride ions diffusion into RC (reinforced concrete) structures is the main cause of deterioration of RC structures, the present study will focus on this phenomenon. Generally, due to chloride diffusion, a concentration gradient develops near the concrete surface. Thus, the time, at which the critical chloride content (threshold value) reaches the steel surfaces and depassivates it, can be regarded as the initiation time of corrosion. The gradient of chloride content is often described by an error function model (RILEM, 1996) which fulfils the condition of Fick's second law of diffusion as shown in Eq. (3):

$$C_{(x,t)} = C_s\left[1 - erf\left[\frac{x}{2(Dt)^{\frac{1}{2}}}\right]\right] \tag{3}$$

where $C_{(x,t)}$ is the chloride content (gradient) at depth x at time t (%/m^3), C_s is the chloride concentration at the concrete surface (%/m^3), x is the depth from concrete surface (m), D is the diffusion coefficient (m^2/s), *erf* is the error function and t is time (s).

The Fick's law is used to describe the diffusion process based on two assumptions firstly, the fluxing species must not react with the matrix and secondly the matrix is homogenous in structure and composition.

Recently, an inclusive ion transport process for predicting of the chloride ingress into reinforced concrete structures has been described by the Nernst-Planck equation [7]. This model, which is well established based on the traditional electrochemical theorem [8], describes the ion transport as a combination of three different mechanisms including: diffusion, convection (carried along by moisture movement, i.e., by absorption or hydraulic pressure), and electrical migration.

Kropp [9] stated that depending on the environmental exposure conditions as well as on the moisture content of the concrete element, the ingress of chlorides into concrete occurs through coupled multiple transport mechanisms. However, most models for chloride ingress in concrete are still based on the Fick's second law of diffusion as the main transport mechanism. Moreover, diffusion-based models such as Refs. [10, 11] have been found broadly acceptable for long-term monitoring of chloride ingress in concrete structures.

Basheer et al. [12] expressed their mathematical model based on Fick's law and incorporated the quantity of chloride binding with the matrix to the equation. Applying the principle of mass conservation

to the concentration of chloride ion couple utilizing Fick's diffusion law yields:

$$\frac{\partial C}{\partial t} = div\left[D_i \nabla (C)\right] - \frac{1}{\omega} * \frac{\partial S}{\partial t} \quad (4)$$

where, C is the free chloride concentration in the porous media (mol/cm^3), S is the quantity of bound chloride ions (mol/cm^3), ω is the content of water in which diffusion occurs (per unit mass of cement), and D_i is the chloride diffusion coefficient in the pore solution (cm^2/s).

Since the diffusion and concentration of chloride ions into concrete and on the reinforcement surface are long-term process, using the proposed potential for accelerated diffusion will be established to determine the diffusivity at any time. Liang et al. [13], by using equation of Tang and Nilsson [14] and considering the influence of the added potential for acceleration, suggested the following expression based on Fick's second law:

$$J_{ix} = -D_e\left[\frac{\partial C_f}{\partial x} - \frac{eFE}{RT}C_f\right] \quad (5)$$

where, J_{ix} is the flux of chloride ion, D_e is the effective diffusion coefficient for the free chloride ion, C_f is the concentration of free chloride ion (mol/L), e is the valency of ion, F is the Faraday's constant (96,500 C/mol), E is the electrical field density (V/m), R = 8.314 (J/mol·K) the ideal gas constant, and T is the absolute temperature (K).

The total chloride ion concentration C_t, in $\delta V = A \times \delta x$ can be obtained from Eq. (6) as follows:

$$C_t = C_b + \varepsilon \cdot d \cdot C_f \quad (6)$$

where, C_b is the bound chloride ion (mol/L), ε the total porosity of concrete, and d the degree of saturation by the pore water solution.

The equation of continuity for the chloride ion is presented by Eq. (7) and shown in Fig. 1:

$$\delta(C_t)A \cdot \delta x = J_x \cdot A \cdot \delta x - J_{(x-\delta x)} \cdot A \cdot \delta x \quad (7)$$

By expanding the Taylor's series and substituting in Eq. (7), it can be rewritten as:

$$\frac{\partial(C_b + \varepsilon C_f)}{\partial t} = \frac{\partial}{\partial x}\left[D_e\left(\frac{\partial C_f}{\partial x} - \frac{eFE}{RT}C_f\right)\right] \quad (8)$$

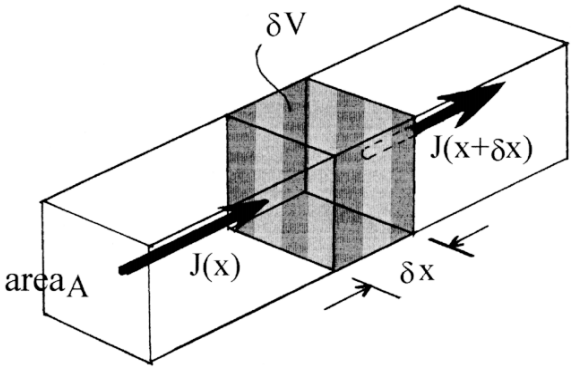

Fig. 1 Scheme for the equation of the continuity of chloride ion.

Assuming that C_f and C_b are parts of a reversible process, the forward and backward absorption rates can be written as Eq. (9) and Eq. (10), respectively:

$$r_a = k_a \cdot \varepsilon \cdot d \cdot C_f \quad (9)$$

$$r_b = k_b \cdot C_b \quad (10)$$

where, k_a and k_b are forward and backward deposition coefficient, respectively. The net absorption rate is shown in Eq. (11):

$$\frac{\partial C_b}{\partial t} = r = r_a - r_b = k_a \cdot \varepsilon \cdot d \cdot C_f - k_b \cdot C_b \quad (11)$$

Eqs. (10) and (11) yield:

$$\frac{\partial(\varepsilon d C_f)}{\partial t} = \frac{\partial}{\partial t}\left[D_e\left(\frac{\partial C_f}{\partial x} - \frac{eFE}{RT}C_f\right)\right] - r \quad (12)$$

If both porosity and the effective diffusion coefficient for mature concrete are independent of space and time, that is, both ε and D_e are constant with respect to x and t, then Eq. (12) can be rewritten as:

$$\varepsilon\frac{\partial C_f}{\partial t} = D_e\left[\frac{\partial^2}{\partial x^2}C_f - \frac{eFE}{RT}\frac{\partial C_f}{\partial x}\right] - r \quad (13)$$

where, $C = \dfrac{C}{C_{en}}$, $\omega = \dfrac{C_b}{C_{bsat}}$, $z = \dfrac{x}{L}$, $\tau = \dfrac{D_e}{\varepsilon d L^2} \cdot t$, $\lambda = \dfrac{eFEL}{RT}$, $\beta = \dfrac{C_{bsat}}{\varepsilon d C_{en}}$.

C_{en} is the chloride concentration at the interface of the concrete surface to the external environment (surface chloride concentration), C_{bsat} is the maximum concentration that can be absorbed by the concrete, and L is the cover thickness of concrete.

From Eqs. (11)-(13) , the non-dimensional Eqs. (14) and (15) can be driven:

$$\frac{\partial C}{\partial \tau} = \frac{\partial^2 C}{\partial z^2} - \lambda \frac{\partial C}{\partial z} - \beta \frac{\partial \omega}{\partial \tau} \quad (14)$$

$$\beta \frac{\partial \omega}{\partial \tau} = \alpha C - \mu \omega \quad (15)$$

where, $\alpha = \frac{k_a L^2 \varepsilon}{D_e}$ and $\mu = \frac{k_b L^2 C_{bsat}}{D_e C_{en}}$.

Eqs. (14) and (15), which were driven simultaneously from the diffusion of accelerated chloride ions in an electric field and the absorption in concrete pores, α, β, λ and μ are all constant with respect to z and τ.

If $C_b \to 0$ then $\omega \to 0$, Eq. (15) should be modified as follows:

$$\beta \frac{\partial \omega}{\partial \tau} = \alpha C \quad (16)$$

Substituting Eq. (16) into Eq. (14), the governing Eq. (17) can be obtained:

$$\frac{\partial C}{\partial \tau} = \frac{\partial^2 C}{\partial \tau} - \lambda \frac{\partial C}{\partial z} - \alpha C \quad (17)$$

Finally, Liang et al. [13] expressed the exact analytical solution by using Laplace transform equation as following:

$$C_{(z,\tau)} = \frac{1}{2} \exp\left\{\left[\frac{\lambda}{2} - \sqrt{\frac{\lambda^2}{4} + \alpha}\right] z\right\} \cdot \left\{ \begin{array}{l} erfc\left[\frac{z}{2\sqrt{\tau}} - \sqrt{\left(\alpha + \frac{\lambda^2}{4}\right)\tau}\right] + \\ \exp\left(z\sqrt{4\alpha + \lambda^2}\right) \cdot \\ erfc\left[\frac{z}{2\sqrt{\tau}} + \sqrt{\left(\alpha + \frac{\lambda^2}{4}\right)\tau}\right] \end{array} \right\} \quad (18)$$

$erfc(x)$ is called the complementary error function and is defined as Eq. (19):

$$erfc(x) = 1 - erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-u^2} du \quad (19)$$

Many researchers have used Fick's second law to predict the initiation time of chloride induced corrosion with a given diffusion coefficient D and surface chloride content C_s, based on the assumption that cement matrix in concrete is chemically inert and evenly porous [15, 16]. However, these hypothesis and models have been challenged since [10] addressed the time-dependent characteristic of chloride transport in terms of D and C_s. Later, Bentz et al. [17] study confirmed the change of D with time.

Crank [18] proposed their model based on the relation between the diffusion and electro-migration of ions in the same electrolyte. Based on Nernst-Einstein equation, if concrete is considered to be a solid electrolyte, the diffusion of charged species i in concrete is related to its partial conductivity σ_i.

$$D_i = \frac{RT\sigma_i}{Z_i^2 F^2 C_i^2} \quad (20)$$

where, D_i is the diffusivity of species i (cm^2/s), R the ideal gas constant (8.314 J/mol·K), T the absolute temperature (K), σ_i the partial conductivity of species i (S/cm), Z_i the charge of species i, F is Faraday's constant (96,500 C/mol), C_i is the concentration of species i (mol/cm^3).

If the partial conductivity σ_i and the concentration C_i are determined, the diffusivity of species i, D_i can be calculated from Eq. (20).

However, the partial conductivity σ_i can be defined as:

$$\sigma_i = \sigma \times t_i \quad (21)$$

where, σ is the conductivity of concrete, and t_i is the transference number of species i, which can be defined as:

$$t_i = \frac{Q_i}{Q} = \frac{I_i}{I} \quad (22)$$

where, Q_i and I_i are the electric quantity and current contribution of species i respectively, to the total electric quantity Q and current I.

If the diffusivity of an ion is to be determined first the Nernst-Einstein equation, and second the transference number of this ion should be known. A simple and proper approach is to make the transference number approximately equal to 1.0. For example, if the concrete is filled with a concentrated salt solution, the transference number may be assumed

as 1.0, and C_i may be considered equal to the chloride concentration in the pore solution, or in the fill the concrete. When $T = 298$ K and $C_{cl^-} = 0.05\ mol/cm^3$. In this model also the chloride diffusion coefficient has been assumed as a constant factor.

3. Mathematical Model of Chloride Diffusion Coefficient

The main weakness and imperfection of the transport process models is the assumption of constant diffusion coefficient for concrete. However, experimental data illustrates that the diffusion coefficient is a function of time.

Mangat and Molloy [19] have proposed the following mathematical relationship to determine the diffusion coefficient as a time-dependent parameter. In this model, the water cement ratio is the only assumed influencing factor on the diffusion coefficient.

$$D_t = D_i \times t^{\left[0.6-25\left(\frac{w}{c}\right)\right]} \quad (23)$$

where, D_i is the chloride diffusion coefficient in the pore solution.

Song et al. [20] introduced their mathematical model based on the time-dependent diffusion coefficient and surface chloride concentration phenomenon shown by Eq. (12). In fact, capillary pores reduce when they are partially blocked as the cement matrix hydrates [21], which implies loss of paths for chloride ions.

$$D_{(t)} = D_0\left(\frac{t_0}{t}\right)^m \quad (24)$$

where, D_t is the diffusion coefficient at time t (m^2/s), D_0 the diffusion coefficient at time t_0 (m^2/s), t_0 the standard time (one year or 28 days), t is time (s), and m is a constant.

4. Database Analysis and Discussion

To conduct analysis, the proposed mathematical model (Eq. (23)) by Mangat and Molloy [19] was selected to compare to available experimental database in literature (Table 1). Based on database, the analysis was performed for various water cement ratio including 0.32, 0.4, 0.54, 0.58 and 0.7.

For every water cement ratio, the magnitude of the chloride diffusion coefficient in different times determined by Eq. (23) and compared to the database experimental results.

Calculated theoretical values and experimental results of chloride diffusion coefficient versus time are presented in Figs. 2-6.

In Figs. 2 and 3, for the concrete with *W/C* ratios 0.32 and 0.4, respectively, there exist a gap approximately $1 \times 10 - 12$ (m^2/s) between the theoretical model and tests results.

For water cement ratio of 0.4 the trend is same but the gap has been increased and mathematical model shows lower diffusion coefficient compare to experimental data. If a service life is design based on the mathematical model, it may show a longer service life than the actual condition of the structure.

In addition, comparison of the diagrams shown in Figs. 3-5 reveals that by increasing the *W/C* ratio in

Table 1 Database for diffusion coefficient.

Diffusion coefficient vs. time			
W/C	*T* (day)	*D* (*10^{-12})	Reference
0.32	1	7.39	Luping and Nilsson (1992)
0.32	3	6.22	
0.32	7	4.93	
0.32	28	3.22	
0.32	90	1.79	
0.32	180	1.74	
0.4	7	3	Polder (1995)
0.4	28	2	
0.4	98	1	
0.54	7	4	Luping and Nilsson (1992)
0.54	28	3	
0.54	98	2.5	
0.58	28	52.3	Mangat and Molloy (1994)
0.58	90	23.8	
0.58	270	10	
0.7	1	45.6	Luping and Nilsson (1992)
0.7	3	26.95	
0.7	7	21.1	
0.7	28	14.5	
0.7	90	15.3	

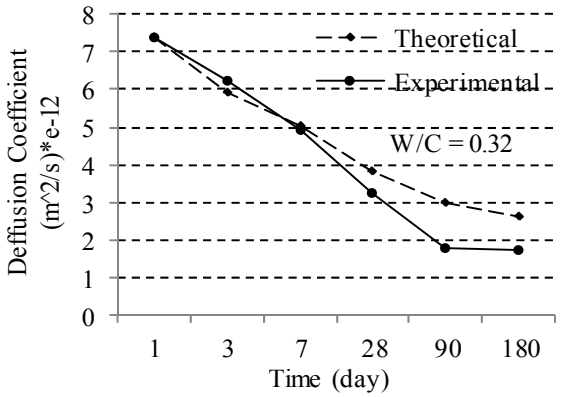

Fig. 2 Chloride diffusion coefficient vs. time for concrete with *W/C* of 0.32.

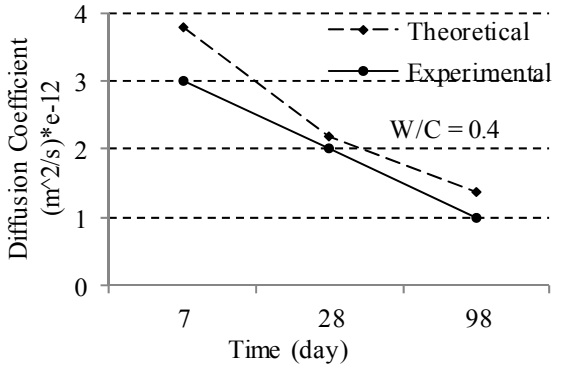

Fig. 3 Chloride diffusion coefficient vs. time for concrete with *W/C* of 0.4.

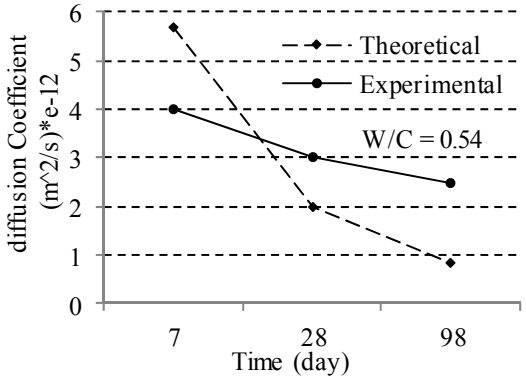

Fig. 4 Chloride diffusion coefficient vs. time for concrete with *W/C* of 0.54.

excess of 0.4, the existing gap between mathematical model and experimental results increases. For instance, when we increase *W/C* ratio from 0.4 to 0.7 the existing gap increases from 1 × 10 – 12 to 15 × 10 – 12 for 90 days (Fig. 5) and from 1 × 10 – 12 to 30 × 10 – 12 for 28 days (Fig. 4).

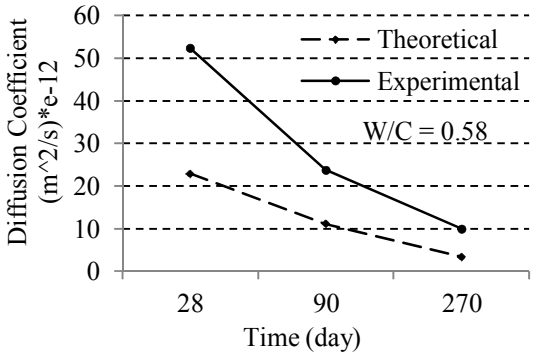

Fig. 5 Chloride diffusion coefficient vs. time for concrete with *W/C* of 0.58.

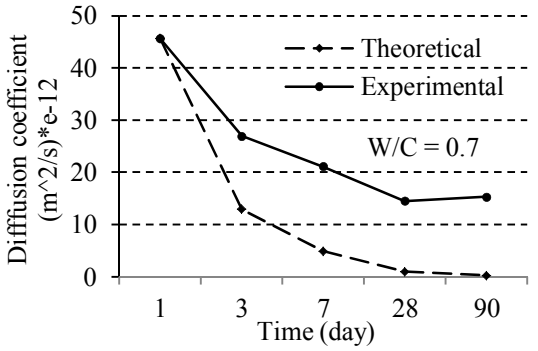

Fig. 6 Chloride diffusion coefficient vs. time for concrete with *W/C* of 0.7.

This study clearly illustrates that up to *W/C* = 0.5, the differences between the mathematical model and experiment results are negligible while the mathematical model shows higher diffusion coefficient. However, beyond *W/C* = 0.5, the differences are getting increased by incising the *W/C* ratio while the experimental results exhibit higher diffusion coefficient.

Also, a review on the experimental results indicate that in some cases with reducing the *W/C* ratio, diffusion coefficient increases, e.g., compare the graphs *W/C* = 0.32 and *W/C* = 0.4, which theoretically, it has to be reduced. This phenomenon proves that there are other influencing factors on diffusion coefficient which has to be taken into account such as proportion and maximum size of coarse aggregate. In order to obtain an accurate mathematical model these factors should be considered as well.

5. Summary and Conclusions

The major source of degradation and deterioration of RC structures is due to the diffusion of chloride into concrete. Many comprehensive studies and investigations have been already conducted to model mathematically this phenomenon. Most of these models are based on Fick's law which assumes that diffusion coefficient is constant and independent of time. Whereas, the experimental results are shown that the diffusion coefficient is a time-dependent parameter.

These mathematical models have been summarized in Table 2.

Two proposed mathematical models by Mangat (Eq. (23)) and Song (Eq. (24)) of diffusion coefficient as a time-dependent parameter were analyzed and compared with experimental database. The presented comparative study on the transfer process of the chloride diffusion versus time, exhibits the gaps between analytical and experimental results (Figs. 2-6).

Table 2 Summary of the mathematical models for chloride diffusion into concrete.

Mathematical model	Presented by reference
$\frac{\partial \phi}{\partial t} = D\frac{\partial^2 \phi}{\partial x^2}$	Fick's second law D, constant
$\frac{\partial \phi}{\partial t} = \nabla.(D.\nabla \phi)$	Fick's second law D, depend on the concentration
$C_{(x,t)} = C_s\left[1 - erf\left[\frac{x}{2(Dt)^{\frac{1}{2}}}\right]\right]$	RILEM Report 14 D, constant
$J_{ix} = -D_e\left[\frac{\partial C_f}{\partial x} - \frac{eFE}{RT}C_f\right]$	Liang et al. [13] Added potential
$D_i = \frac{RT\sigma_i}{Z_i^2 F^2 C_i^2}$	Crank [18] D, depends on partial conductivity of species
$\frac{\partial C}{\partial t} = div[D_i \nabla(C)] - \frac{1}{\omega} * \frac{\partial S}{\partial t}$	Basheer et al. [12] Effect of chloride binding capacity (free chloride)
$D_t = D_i \times t^{\left[0.6-25\left(\frac{w}{c}\right)\right]}$	Mangat and Molloy [19] D, a function of *W*/*C* ratio
$D_{(t)} = D_0\left(\frac{t_0}{t}\right)^m$	Song et al. [20]

These gaps reveal that influence of the other responsible parameters in addition to water cement ratio such as aggregate size, temperature and humidity must be included precisely in the mathematical models.

To predict the service life of RC structures accurately, the deviation of the chloride diffusion coefficient with time should be determined. Subsequently, an appropriate mathematical model has to be proposed to model the diffusion coefficient at any given time intervals accurately.

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Statistical Significance of Reduction in Load Bearing Properties of Crude Oil Contaminated Soil in Kwale, Niger Delta

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Abstract: The Niger Delta has experienced tons of crude oil spill within their environment over the years and its impact on the environment is quite lethal. The soil is a major recipient of this spilled crude. When contaminated with crude oil, the load bearing capacity is consequently affected. This study aimed at providing a statistical evidence to prove that the impact of crude oil contamination on the soil's bearing capacity is significant. Four samples of uncontaminated soil of Kwale were collected and analyzed for their load bearing properties: cohesion (c), angle of internal friction (θ^o) and bulk density (γ). These soil samples were polluted with crude oil in levels of 5%, 10%, 15% and 20% and compared with intact soil. A consistent reduction was observed in the bearing capacity as the crude oil level increased. Using the SPSS (statistically package for social sciences), the significance was tested at the various contamination levels at a 5% confidence level and the result showed significance at 15% and 20% levels with calculated P-values of 0.038 and 0.035 respectively for both the square and strip foundation footings.

Key words: Bearing capacity, soil, contamination, crude oil, environment.

1. Introduction

The frequency of oil spill has been on a steady increase in most of the oil producing communities in the Niger Delta region of Nigeria. The impact is lethal and multidimensional. The soil bearing capacity which is the ability of the soil to support structure load is the first to receive the brunt of this phenomenon when it occurs. Crude oil, when spilled, moves both vertically, by gravity and horizontally, as it flows and spreads throughout the length and depth of the receiving soil, destroying the vegetal, terrestrial and aquatic environments. According to Pamukcu and Hijazi [1] the spillage of hydrocarbon liquid moves downward under gravity partially saturating the soil in its path towards groundwater level. Generally hydrocarbon is more viscous than water, therefore it relatively moves slower within the groundwater body Zulfahmi et al. [2].

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Several studies investigating the effects of hydrocarbon on the engineering properties of the soil have been carried out. Evgin and Das [3], using triaxial tests examined the effects of crude oil on contaminated clean sands, and Shin and Das [4] also studied the effect of crude oil on load bearing capacity of sand at oil contents ranging from 0% to 6%. Khamehchiyan et al. [5] investigated the effects of crude oil contamination on geotechnical properties of clayey and sandy soils. Aiban [6] examined the effects of temperature on engineering properties of oil contaminated sand in Kuwait, while Oku [7] studied the spatial variation of soil properties on oil spillage sites in the Niger Delta, Nigeria. All these studies agreed on the reduction of soil strength due to crude oil, but none explored whether this reduction in soil strength is statistically significant.

This study, therefore, aimed at investigating the statistical significance of the reduction in the load bearing properties of the Kwale soil due to crude oil

contamination.

2. Material and Methods

2.1 Study Location

Kwale is one of the major towns in Ndokwa West LGA (Local Government Area) of Delta State and the headquarters of the LGA, Ndokwa West. A large expanse of the land has been used up by the oil field with several oil wells. This made the neighboring communities highly vulnerable to spills. The area experiences double rainfall peaks in June/July and September/October, with an average temperature of 30 ^{o}C [8]. The heavy precipitation assists in the downward movement of oil to the ground water table.

2.2 Experimental Procedure and Design

To generate the data set for this study, four soil samples were collected from four boreholes in the study area and analyzed through appropriate laboratory tests. These samples were collected using the hand auger. Triaxial tests were conducted on the remolded soil samples before and after contamination. The bulk density, height, diameter and initial moisture content of the specimen were determined. The specimen was then enclosed with rubber membrane and mounted on the base of the triaxial cell with solid end caps placed on either ends. With the triaxial cell placed in the compression machine, hydrostatic pressure as required was applied and kept constant till the end of the experiment. The test was repeated on two identical specimens with increasing pressure. Mohr circles were drawn for each test at failure and a common tangent drawn to the Mohr circles gave the failure envelope from where the parameters cohesion (c) and angle of internal friction (θ^{o}) were determined. This was done for all the four borehole samples and the results presented in Table 1.

2.3 Hypothesis

The hypothesis adopted in this study, H_o is that the reduction due to crude oil spill on the bearing capacity of crude oil contaminated soil is not significant.

Table 1 Summary of triaxial test results.

Bore hole number	Depth	Percentage oil (%)	Bulk density (g/cm^3)	Cohesion (kN/m^2)	Angle of internal friction (θ^{o})	Bearing capacity (kN/m^2)	
						Square footing	Strip footing
	1.5	0	2.07	84	32	1,154.97	975.95
	1.5	5	2.11	23	5	88.18	75.82
1	1.5	10	2.10	14	3	59.23	51.74
	1.5	15	2.11	11	2	4,959.00	43.70
	1.5	20	2.10	10	2	46.30	40.95
	1.5	0	2.09	57	20	362.24	308.50
	1.5	5	2.07	45	15	236.49	201.58
2	1.5	10	2.11	33	10	146.04	124.94
	1.5	15	2.09	113	2	55.88	48.88
	1.5	20	2.10	8	2	39.87	35.59
	1.5	0	2.10	76	27	777.70	662.40
	1.5	5	2.09	60	22	482.93	412.02
3	1.5	10	2.10	24	8	111.39	96.05
	1.5	15	2.10	18	7	88.35	76.85
	1.5	20	2.10	18	6	88.35	76.85
	1.5	0	2.08	68	23	539.50	459.11
	1.5	5	2.11	52	18	334.30	285.28
4	1.5	10	2.11	38	13	204.55	174.96
	1.5	15	2.09	26	9	118.98	102.36
	1.5	20	2.10	23	8	107.55	92.85

The objective of this hypothesis was to determine whether the reduction observed in the bearing capacity of crude oil contaminated soil of Kwale, is statistically significant. To test this hypothesis, paired sample *t*-test was used and the results presented in Tables 2a and 2b.

The bearing capacity values for square and strip footings, for each borehole sample were calculated using Terzaghi's bearing capacity theory with the relevant bearing capacity factors as follows:

for square footing:

$$q_u = 1.3cN_c + \gamma D_f N_q + 0.4\gamma BN\gamma \quad (3)$$

for strip footing:

$$q_u = cN_c + \gamma D_f N_q + 0.5B\gamma N\gamma \quad (4)$$

where, N_c, N_q and $N\gamma$ are bearing capacity factors assumed by Terzaghi, and c is cohesion, D_f is foundation depth, B is foundation width, γ is bulk density

3. Results and Discussion

From Table 1 for borehole sample 1, at 0% contamination (control), the bearing capacities were 1,154.97 kN/m^2 and 975.95 kN/m^2 for square and strip footings respectively. At 5% contamination (observed) they dropped drastically to 88.18 kN/m^2 and 75.82 kN/m^2, respectively. The bearing capacity at 10%, 15% and 20% (observed) where recorded as 59.23 kN/m^2 and 51.74 kN/m^2, 49.59 kN/m^2 and 43.7 kN/m^2, and 46.30 kN/m^2 and 40.95 kN/m^2 for both square and strip footings, respectively. Similarly for the other three borehole samples the bearing capacity values were as recorded in Table 1.

Table 3 presented the summary of the mean values of the bearing capacity of Kwale soil at the various contamination levels. It was clearly evident that there was a consistent reduction in the values from 708. 603 kN/m^2 and 601.49 kN/m^2 down to 70.518 kN/m^2 and 61.56 kN/m^2 at 0% and 20% contamination levels for the square and strip footings respectively. These results were used for the statistical analysis employing the SPSS (Statistically Package for Social Sciences).

From the statistics in Tables 2a (i-viii), the tests were conducted on the paired mean values of the bearing capacity for square and strip footings at 0% and 5%, 0% and 10%, 0% and 15%, 0% and 20% for all the borehole samples. The paired sample statistics in Table 2a (i) showed the paired bearing capacity at 0% and 5%, whose mean values were 708.603 kN/m^2 and 285.475 kN/m^2. N in column three indicated the number of samples which is 4. The standard deviation and standard error were presented in columns 4 and 5. Table 2b (i) presented the actual statistical test of the paired samples. At 95% confidence interval the level of significance was 0.147 on a two tailed test. Also in Table 2a (ii), the bearing capacity at 0% was paired against that at 10% (708.603 kN/m^2 against 130.303 kN/m^2). The result of the test showed a significance level of 0.061 shown in Table 2b (ii). In the same vein, in Tables 2a (iii-iv) and 2b (iii-iv), the results of the paired tests were 0.038 and 0.035 for 0%/15% and 0%/20% pairs. The results of the hypothesis showed a significance level of 0.038 and 0.035 at 15% and 20% contamination levels respectively indicating statistical significance. These results recorded in Tables 2a and 2b (i-iv) were for square footing.

The strip footing results were presented in Tables 2a and 2b (v-viii). Similar tests were conducted and the results showed that at 15% and 20% contamination levels the test of significance indicated 0.038 and 0.035 respectively while at 5% and 10% the levels of significance were 0.147 and 0.061, respectively.

About decision rule, the null hypothesis is accepted if the calculated value is greater than 0.05 ($P > 0.05$), otherwise it is rejected and the alternative, which is, the research hypothesis, H_1 is accepted. The result of the only null hypothesis showed that the calculated *P*-values at 5% and 10% contamination levels were more than 0.05 ($P < 0.05$). The null hypothesis was therefore accepted at that point while the alternative which is the research hypothesis was rejected. Furthermore at 15% and 20% contamination levels, the calculated *P*-values of 0.038 and 0.035 for both the square and strip footings respectively were

Tables 2 Paired sample *t*-test (a and b).

(a) Paired sample statistics square footing (i)				
Pairs	Mean	N (number of samples)	Standard deviation	Standard error mean
Pair 1 BC_{square} 0%	708.6030	4	342.82213	171.41107
Pair 1 BC_{square} 5%	285.4750	4	166.02932	83.01466
Paired sample statistics square footing (ii)				
Pair 2 BC_{square} 0%	708.6030	4	342.82213	171.41107
Pair 2 BC_{square} 10%	130.3025	4	61.01733	30.50866
Paired sample statistics square footing (iii)				
Pair 3 BC_{square} 0%	708.6030	4	342.82213	171.41107
Pair 3 BC_{square} 15%	78.2000	4	32.05592	16.02796
Paired sample statistics square footing (iv)				
Pair 4 BC_{square} 0%	708.6030	4	342.82213	171.41107
Pair 4 BC_{square} 20%	70.5175	4	32.73714	16.36857
Paired sample statistics strip footing (v)				
Pairs	Mean	N	Standard deviation	Standard error mean
Pair 1 BC_{square} 0%	601.4900	4	288.70142	144.35071
Pair 1 BC_{square} 5%	243.6750	4	141.44293	70.72146
Paired sample statistics strip footing (vi)				
Pair 2 BC_{square} 0%	601.4900	4	288.70142	144.35071
Pair 2 BC_{square} 10%	111.9225	4	51.69478	25.84739
Paired sample statistics strip footing (vii)				
Pair 3 BC_{square} 0%	601.4900	4	288.70142	144.35071
Pair 3 BC_{square} 15%	67.9475	4	27.17220	13.58610
Paired sample statistics strip footing (viii)				
Pair 4 BC_{square} 0%	601.4900	4	288.70142	144.35071
Pair 4 BC_{square} 20%	61.5600	4	27.76125	13.88063

(b) paired samples test (i) square footing								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed)
				Lower	Upper			
Pair 1	423.12750	434.62736	217.31368	-268.46162	1,114.71662	1.947	3	0.147
Paired Samples Test (ii)								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed)
				Lower	Upper			
Pair 2	578.30000	394.04972	197.02486	-48.72104	1,205.32104	2.935	3	0.061
Paired samples test (iii)								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed)
				Lower	Upper			
Pair 3	630.40250	355.02706	177.51353	65.47522	1,195.32978	3.551	3	0.038
Paired Samples Test (iv)								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed)
				Lower	Upper			
Pair 4	638.08500	349.40232	174.70116	82.10794	1,194.06206	3.652	3	0.035

(b) Paired samples test (v) strip footing								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed)
				Lower	Upper			
Pair 1	357.81500	366.26339	183.13170	-224.99179	940.62179	1.947	3	0.146
Paired Samples Test (vi)								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed
				Lower	Upper			
Pair 2	489.56750	331.98725	165.99362	-38.69829	1,017.83329	2.949	3	0.060
Paired samples test (vii)								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed)
				Lower	Upper			
Pair 3	533.54250	298.86540	149.43270	57.98096	1,009.10404	3.570	3	0.038
Paired samples test (viii)								
	Paired differences							
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		*t*	df	Significance (2-tailed)
				Lower	Upper			
Pair 4	539.93000	294.17820	147.08910	71.82684	1,008.03316	3.671	3	0.035

Table 3 Mean bearing capacity values.

S/N	Percentage of oil contamination	Bearing capacity (kN/m^2)	
		Square footing	Strip footing
1	0	708.603	601.490
2	5	285.475	243.683
3	10	130.303	111.923
4	15	78.200	67.948
5	20	70.518	61.560

less than 0.05 ($P < 0.05$), the null hypothesis was rejected while the research hypothesis was accepted. This suggests therefore that at higher crude oil pollution levels the impact is significantly high. This finding is consistent with the findings of Shin and Das [8] which indicated that the load bearing capacity of the soil drops significantly with increase in crude oil content.

4. Conclusion and Recommendations

From the study, it became evident that statistically speaking, the impact of crude oil spill on the soil is significant to cause appreciable damage to the soils load bearing properties in Kwale, an oil producing community, at beyond 10% contamination. It therefore becomes imperative for the oil operators to apply every reasonable means to drastically reduce if not completely eliminate spillage in the environment especially within the host communities. Furthermore, deliberate policies and enabling laws ought to be enacted to specifically address spillage issues, and implementation pursued vigorously to mitigate impacts.

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Durability of Stress Ribbon Bridge Checked during Loading Test

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Abstract: Stress ribbon bridges have many advantages and became recently more popular mostly because of their versatile form, slender decks giving a light aesthetic impression and durability assured by post tensioned concrete. The paper presents the first in Poland stress Ribbon Bridge constructed last year. A static and dynamic analyse of the model is presented as well as construction solutions which were used to achieve the highest durability. The bridge was checked during static and dynamic load test. The results of this prove test were compared with results obtained from examination and study of other different bridge structures. It confirmed that the bridge has good dynamic resistance and greater stiffness than assumed in the design.

Key words: Footbridges, stress ribbon bridges, loading test, bridge dynamic.

1. Introduction

In 2009 as a result of a sudden flood in Polish Carpathian Mountains, a small bridge shortening significantly the way and situated over the torrent river at the subdivisions was destroyed. Local authorities were forced to hold a tender for the new foot and road bridge which was supposed to be as well cheap and fast to build and as durable and easy to use.

The winner of bidding was a contractor company IMB Podbeskidzie Ltd., which in cooperation with DHV Poland Ltd., has made the most attractive economically and qualitatively offers for prestressed concrete ribbon bridge which was new for Polish conditions (Fig. 1). The proposed construction of bridge has gained approval of investors due to its characteristics mentioned in list as follow:

(1) Aesthetics: The bridge is designed as “quiet” and slender in shape, harmonizing with natural mountainous landscape;

(2) Low price: The design uses an innovative solution which allows lowering the price (pre-stressed concrete ribbon structure, execution without expensive shuttering, foundation on Cutter Soil Mixing Barets);

(3) Durability: The use of modern and high strength materials allows the utilization of the bridge for more than 100 years (a high quality compressed concrete C 50/60, stressing tendons and anchors secured with concrete);

(4) Fast implementation: The design and the construction of bridge took seven months which can be shortened by better team coordination;

(5) Features: Besides foot crossing (4 kN/m^2) it was supposed to enable driving vehicles up to 15 t when the road was 2.75 m wide;

(6) Moreover, because of local hydrological and ecological conditions it was supposed to have the span at least 70 m long matching the mountainous landscape.

2. Structure Description

The foundation of the bridge was made in CSM (cutter soil mixing) technology as cement soil barrettes.

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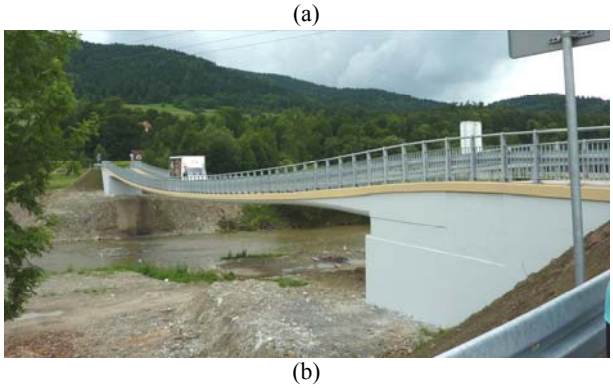
(a)



(b)

Fig. 1 (a) Damaged in a flood bridge; (b) a view of the new structure.

This solution improved radically mechanical properties of existing soil base. Together with cement mortar soil makes substance which is homogeneous and guarantees compression strength greater than 12.5 MPa. Such formed foundation blocks work both with the base and side surfaces which increase the resistance of friction on the side surfaces and the resistance pressure at the front of the foundation. In order to ensure its stability 12 permanent anchors were used with a length of 18.5 m (Fig. 2).

Ribbon Bridge with a length of 91.4 m and the distance between supports 71.4 m is 5.54 m wide with a total structural height 47 m (Fig. 2). It was made of concrete C50/60 stressed by cables consisting of 12 and 19 strands. Precast elements of the bridge of the length about 3 m were suspended for eight tendons anchored in the concrete solid abutments. The edge segments 7.5 m long on the both sides were made on stationary scaffoldings.

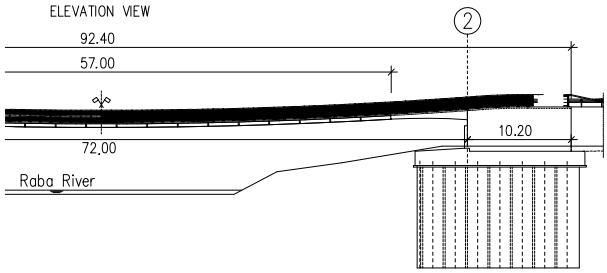
While designing the bridge a special attention was put on the durability in terms of large, cyclic concentrated loads from vehicles. Because of that the construction had to meet higher standard requirements than footbridges loaded only with crowds of pedestrians. Construction solutions [1, 2] which were used to achieve the highest durability are:

(1) Reduced stress of the entire length of the deck while allowing a small tensile stresses in the concrete. The only exceptions are the joints of the in-situ and precast parts, where soft reinforcement was increased to a level that cracks did not exceed 0.1 mm;

(2) Using steel pipes as shields of bearing tendons, which besides protecting the cables against damage during assembly of precast segments are an additional reinforcement of tensile and shear forces in the bridge providing additional protection against corrosion;

(3) Including all the tendons into the system carrying live and thermal loads. Ribbon bridge, after completion works as the composite structure. The share of reinforcing and stressing steel in total cross-section of a concrete system is significant and very effectively increases the stiffness of the whole structure.

The author assembled prefabricated suspension system that allows assembling into cables and carrying to the destination (Fig. 3). Also concreting supporting sections was designed in a way that formworks could be hung on the load-bearing cables. The solutions allowed to reduce costs significantly



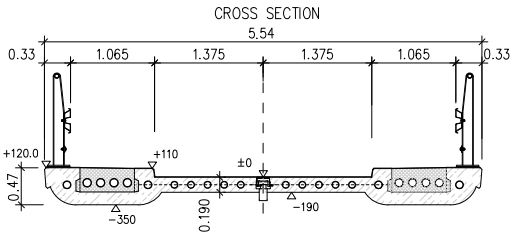


Fig. 2 Longitudinal and transverse section (unit: m).

Fig. 3 Concreting and assembly of precast bridge elements.

accelerate the time of its implementation. After installation of precast segments closing support sections were made in-situ. Stressing was started after seven days of concreting. Stressing works required great precision, because the forces in the tendons were affecting directly the deformations of the structure. Therefore, the stressing force was applied in three stages, and the work was carried out with two jacks with two symmetrical tension cables on the one side of the bridge. The last stage was concreting the bays in the abutments in the location of tendon heads and technological breaks in the abutment and making corrosion protection as well as assembling equipment.

Static analysis of the bridge included geometrically and material changeable system which was a result of the accepted erection stages and rheological processes of the concrete and stressing steel. Calculations were done using the bridge nonlinear analysis taking into account the stages of the bridge assembly. Each next step of calculations took into account the deformations of the preceding stages. Control measurements carried out during the construction of the bridge confirmed the very good compatibility of predicted forces in cables and deformations of the bridge elements in different stages of the construction (Table 1) [3].

Dynamic calculations were done to determine the risks associated with the sensitivity of the dynamic structure and pedestrian comfort. The deep analysis of the numerical model was held using numerical solving equations of motion. The bridge was loaded with the few schemes of load simulating different cases of pedestrian load, using the universal model (1) elaborated by Seiler and Huttner [4] which is shown in Figs. 4 and 5.

$$F(t) = \begin{cases} G \cdot [1 + s \cdot \cos(2 \cdot \pi \cdot f_G \cdot t)] \leftarrow -\frac{t_c}{2} < t \leq \frac{t_c}{2} \\ 0 \leftarrow \frac{t_c}{2} < t \leq T - \frac{t_c}{2} \end{cases} \quad (1)$$

where,

G: load of a pedestrian or a group of pedestrians;

s: dynamic pulse rate;

f_G: analyzes frequency of oscillations;

T: period of vibration;

t_c: time of contact of the foot with the ground.

Besides the case of crossing vehicle was simulated alternatively. Firstly, as one dimensioned oscillator loaded by timeline function, and next as continuous vehicle cross with taking into account variable vehicle position together with deck deflection. Vehicle speeds (10, 20, 30 km/h) were the same as excitations used later during the load test.

Basic natural frequencies and modes are shown in (Fig. 6), as far as vertical vibrations are concerned there is only one mode with frequency 1.93 Hz in the range of critical values (1.6-2.4 Hz) [3]. The following two can caused some doubts only in the case of too small damping. As far as lateral vibrations are concerned the first not shown here mode has frequency 4.67 Hz and is completely beyond the critical range (0.7-1.3 Hz). Therefore in theoretical and experimental analysis it was decided to focus on the three modes of the following frequencies 1.93, 2.62 and 3.09 Hz.

Table 1 Superstructure displacements in each stage during execution (middle of the span).

No.	Stage	Superstructure sag (mm)	
		Calculated value	Measured value
1	Assembling of bearing cables	500	500
2	Assembling seven prefabricates	2,195	2,187
3	Pulling bearing cables with seven prefabricates	1,350	1,350
4	Assembling 12 prefabricates	2,045	2,030
5	Pulling bearing cables with 12 prefabricates	1,115	1,025
6	Concreting holes in prefabricate and deck section	1,425	1,427
7	Pre-stressing superstructure	1,400	1,395

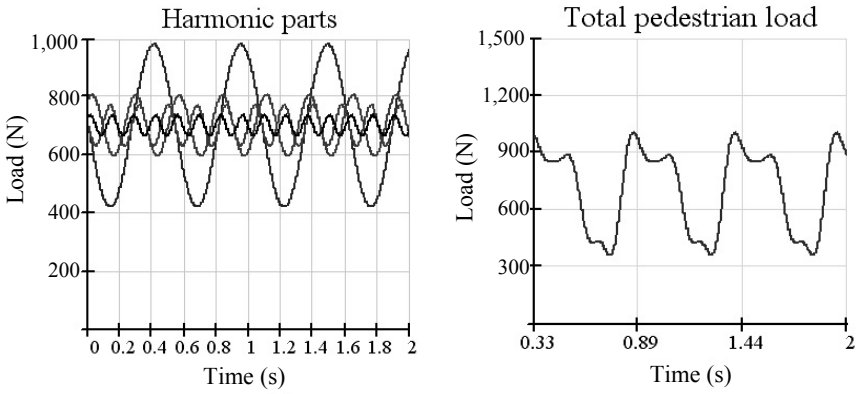


Fig. 4 Model of pedestrian load—marching [4].

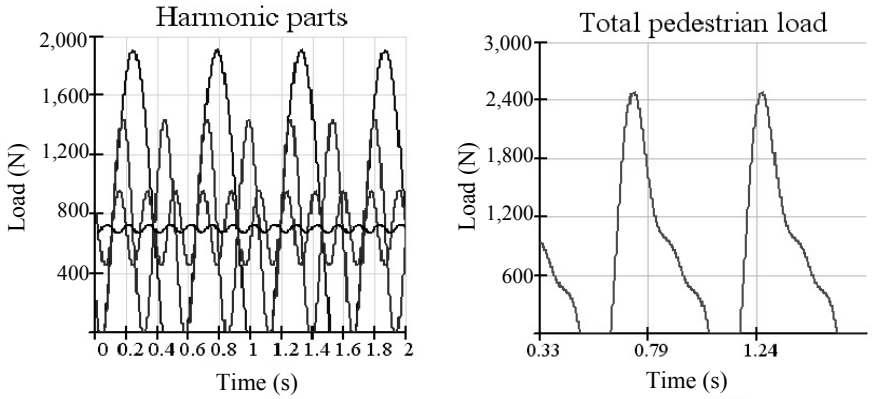


Fig. 5 Model of pedestrian load—jumping [4].

3. Load Test

The program of load test was more extensive then in case of typical road bridge. A number of situations were arranged that could occur during the use of the footbridge. Dynamic action of a crowd was simulated by a group of a dozen or so people. Columns of pedestrians marching rhythmically, people running and crossing by disorderly groups of various numbers of people were the cases investigated. Each of these was done twice in each direction. A single person also rhythmically walked across the footbridge both ways. Malicious actions were performed by rhythmical jumping of several persons in spots of the structure indicated as sensitive. And finally, a dynamic response to a special vehicle (loaded fire truck with weight 151 kN) driving across the bridge was studied.

Measurements were made with the set consisted of the following main components: portable computer, 16-bit measurement card with conditioner and a set of

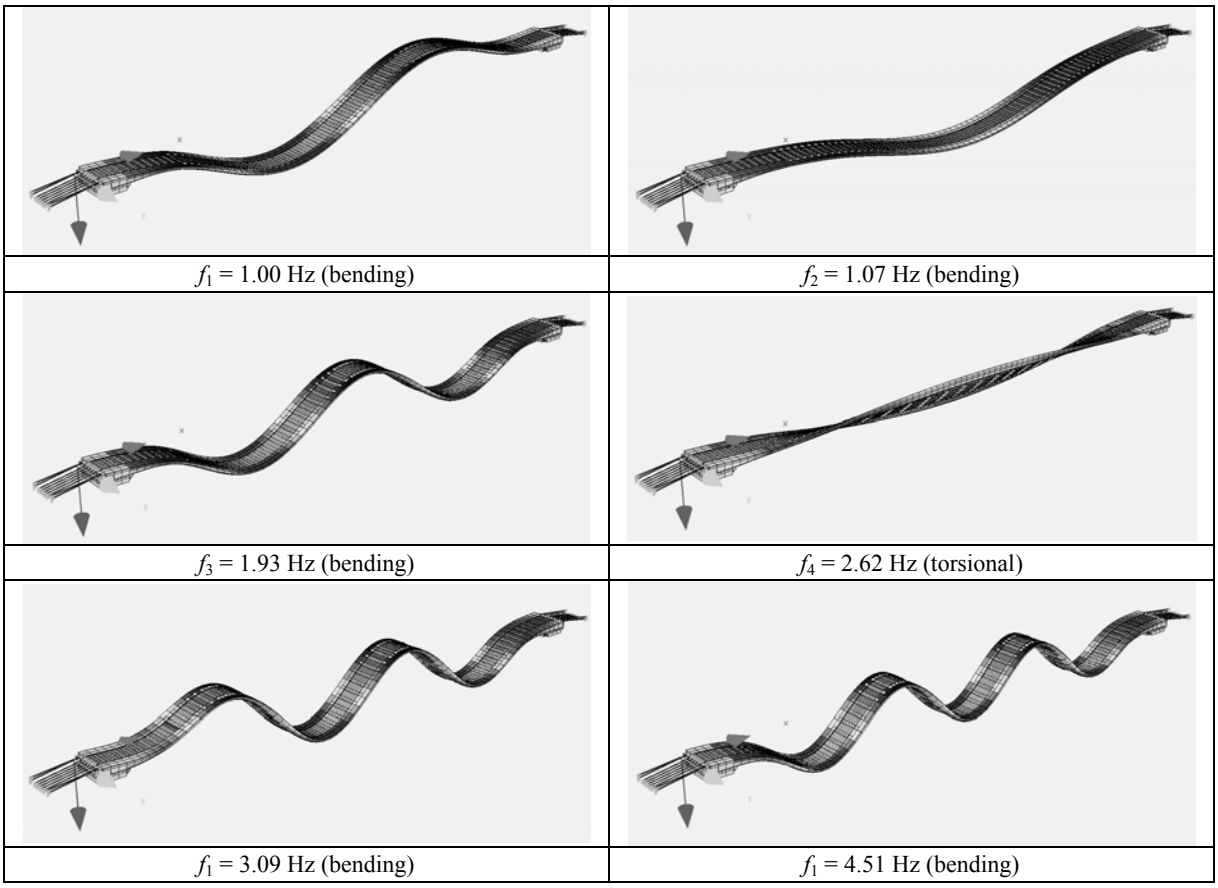


Fig. 6 Basic natural frequencies and modes.

displacement sensors and accelerometers (Fig. 7). The set enables simultaneous recording of results on 16 channels at a rate of 100 Hz. The analysis of the recorded results was aimed mainly on determining the principal dynamic features of these structures, such as dynamic resistance and probability of resonant phenomenon. This was accomplished by way of identifying system parameters, such as natural frequency, form of free vibration and degree of damping expressed in the form of LDD (logarithmic damping decrement). Table 1 presents basic results compared to other five footbridges tested by our team recently [5]. Structural schemes of these bridges are shown in Fig. 7.

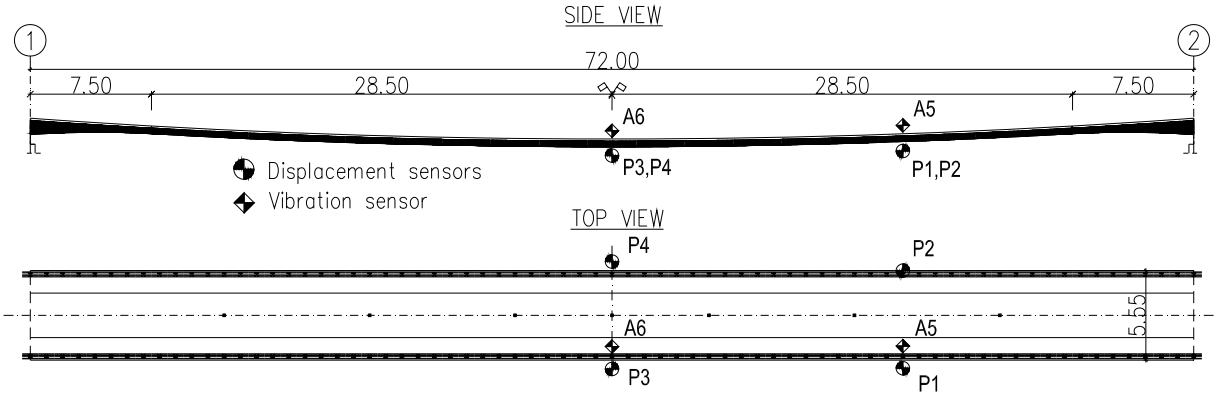


Fig. 7 Location of measuring points.

Deflection in static test caused by the vehicle standing in the middle of the span was 23.5 mm with non-significant displacement of cable anchorages (up to 0.1 mm). It stated 45% of the theoretical deflection obtained in the initial model which assumed larger elasticity of anchorage blocks (even 1 mm). After the model revision compatibility was on the level of 92%.

It was possible to identify first four modes of vibrations (Table 2) which natural frequencies were close to the theoretical (Fig. 6). The author's team has tested many different bridges, also for pedestrians [6-8]. Measured damping values are small comparing to other tested footbridges (Fig. 8) described in Ref. [5] but similar to those written in bibliography [1, 3, 8, 9]. Damping nonlinearity and amplitude dependence is very distinctive. The value of damping decreases together with decreasing amplitudes.

The vehicle crossings with different speeds allowed to determine a DAF (dynamic amplification factor), which is defined as a relation of maximal deflection obtained in passing with the given speed to deflection measured during quasi-static passing with speed 5 km/h. DAF values are between 1.01 and 1.07 and are greater than standard dynamic coefficient which is equal 1.0. Selected results (deflections and accelerations) caused by pedestrians are listed in Table 3.

4. Conclusions

Constructing the first stress ribbon bridge in Poland gave Polish bridge engineering society valuable

Table 2 Results of a load test in comparison to results from other tested footbridges.

Footbridge	Frequency f (Hz) vibration modes				Damping ζ (%) vibration modes				Span length	Stiffness	
	1	2	3	4	1	2	3	4	(m)	Deck EI ($MN \cdot m^2$)	Structure (kN/mm)
Chorzów	1.62	2.07	3.19	3.38	1.34	1.67	1.46	1.26	46	510	0.83
Ruda	1.02	2.05	2.45	3.23	0.70	4.69	1.78	0.54	55	2,330	3.23
Uniwersytecka	1.17	2.53	2.77	3.17	2.88	2.80	2.50	2.04	63	4,890	2.33
Kielce	2.06	2.26	2.48	3.31	2.16	2.91	2.07	1.70	37	420	0.65
Murckowska	1.74	3.24	3.92	4.21	0.52	0.80	1.86	2.11	41	1,500	2.17
Lubien	1.08	1.20	1.96	2.60	0.67	1.00	0.35	0.75	71	355	3.57

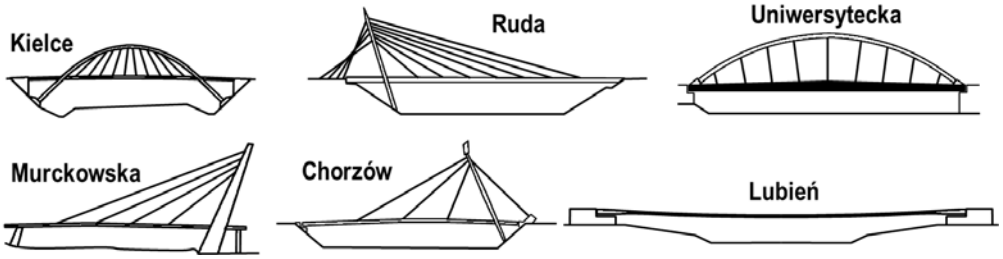


Fig. 8 Structural schemes of footbridges taken to comparison.

Table 3 Measured deflections and accelerations caused by selected excitations.

Type of excitation	Deflection (mm)	Acceleration (m/s^2)
March of 1 persons synchronized with 3rd mode	0.40	0.01
March of 15 persons non-synchronized	2.09	0.03
Run of 1 person synchronized with 4th mode	0.44	0.07
Run of 15 persons synchronized with 4th mode	4.07	0.49
Jumps of 15 persons synchronized with 3th mode	1.85	0.30
Jumps of 15 persons synchronized with 4th mode	9.71	1.75

Fig. 9 15 tons car driving with 30 km/h speed during load test.

experience of designing and erecting such structures. It is a very valuable experience because a new, even more complicated structures are already in the final stages of design [10]. It was confirmed that they can be successfully applied in construction of light crossings like footbridges or small road bridges reaching high structure durability, aesthetical view and low costs. This kind of structure has also a few important advantages to be mentioned. First of all, short erection time thanks to using precast elements and assembly without frameworks by hanging to main cables. It allows erection over difficult terrain obstacles. Besides, high stiffness and long working life was gained thanks to applying high strength concrete and deck stressing by tendons with cement injection. The results of load test confirmed that the bridge has good dynamic resistance and greater stiffness than assumed in the design (Fig. 9).

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Application of the Principles of Lean Thinking in the Post Construction Department

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Abstract: The increase on the competitiveness, the search on the customer satisfaction, the search by reducing waste in the civil construction were facts which helped entrepreneurs and companies to seek new ways of working, being lean construction one of the ways to get that. Studies report that the application of the lean tools in construction was carried out in an isolated way. This type of application was pointed as a major factor limiting the extent of achievement in implementing lean principles. The aim of this studies is to identify opportunities to implement the principles of lean production in the service department of a construction company in Goiás, proposing routines that try to implement the continuous improvement of its processes, eliminating waste, reducing the lead time, allow it to perform the mapping processes, applying the just-in-time and among others, providing services that add value to the customer satisfaction. It was possible to establish the average time for each step, allowing to identify possible improvements in the department, from the perspective of lean principles. The research paper concludes by pointing out the activities for the Department of Post Construction work from building companies, from lean concepts.

Key words: Lean production, lean thinking, technical assistance, post construction.

1. Introduction

Civil construction is extending and it is changing the thinking of many entrepreneurs. From 1990, the growing competition between companies, the increasing on the costumer's requirements and the reduction of financial resources were important facts for changing the company's way of thinking, encouraging companies to seek the highest levels of performance through investments in management and production technology [1-3].

Many companies believed that one way to gain competitive advantages are summarized in the adoption of some initiatives that generate increased productivity and quality in their products. Some managers in an attempt to combat the competition tried to join the new management in an impulsively way, without planning and knowledge. Within this scenario, the use of lean practices, from the TPS (Toyota Production System), presented as an alternative capable of providing greater productivity and competitiveness for organizations [4]. It happens due to the fact that lean construction is based on the success of all processes and it is directly related to their management [5].

Due to the productivity gains and the reduced rates of waste on construction site, several civil construction companies found out ways to improve its process with the implementation of the lean principles into the companies [6].

Costa et al. [2] emphasize in their studies that the literature still debates a little about the strategic issues involved in implementing the concepts of lean construction.

Civil construction activities are complex and present some specific characteristics. Picchi [7] points out some opportunities with regards to the application of these concepts in some areas of civil engineering that have not been explored yet, such as the Post Construction Department at Construction Companies, or those that were implemented in an isolated way. This is the reason that provided some limitations regarding

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the extension of the results obtained and new opportunities for the integration of concepts [6].

1.1 Literature Review

For the structure of this work, five lean principles were used such as: flow, value stream, value, pull and perfection and they are all proposed by Womack and Jones [8], due to its broader scope and due to the fact that it is more widely used in industry [7].

Continuous improvement of production, the maximum satisfaction of customers, the use of less resources and elimination of waste on the process are some of the goals that the lean principles try to achieve within the organizations [2]. Authors like Nahmens and Ikuma [9] cited the importance of the application of lean tools to provide a safer working environment for employees, reaching occupational accident rates that were 58% lower when compared with those companies that did not use the lean tools. The concepts of the principles can be contextualized as follows:

Understanding what is the value for specific products from the point of view of the final customer, it is the first major challenge of the implementation of lean construction [10], which is a process that identifies what is value for customers by offering products with higher aggregates value, without waste and with values that customers are willing to pay. It is necessary that the decision of building companies to produce certain products is based on the needs and desires of its target customers and not only the productive capacity of the organizations [6, 7, 11-14].

Identifying the value stream consists of separating actions of the production process into three types of actions: actions that add value to the end customer, actions that do not add value but are important for maintaining the quality of products and processes and actions that do not add value and should be eliminated immediately [13]. The objective of the value stream mapping is to understand the processes flow, materials, people and equipment. It helps to reduce the variability of products, waste and transparent procedures [6, 7, 11, 12].

Getting a continuous flow processes, it is intrinsically linked to the transparency and knowledge of the execution steps of the product. Obtaining the continuous flow involves several departments, since interruptions cannot occur; therefore changing the mindset of the organization and support of the management are important facts to achieve this goal. Benefits such as reduced lead time, which represents the time of product design, order processing and inventory, eliminating waste and adding value to the final customer are consequences of the implementation of a continuous production flow [6, 7, 11-13, 15].

The pull production allows the company to produce their products from the final customer demand (Takt Time), and in the right quantity at the right time (just-in-time), thus smaller amounts of stocks, elimination of waste or unproductive time and increased on productivity are some benefits achieved [6, 7, 11-13].

Perfection matches in the pursuit of continuous improvement, the search for improvement, continuous learning, transparency and standardization of processes, rapid fault detection and problem's solution of waste disposal are some of the ways to raise the performance of products seeking improvements [6, 7, 11-13].

Among the opportunities for implementing lean thinking in construction, Picchi [7] cites some tools that can assist in the integration of concepts until their implementation. Table 1 is a proposal of adapted tools from Picchi [7] for better visualization of lean principles in Post Construction Department.

1.2 Objectives

The objective of this research is to identify the opportunities on the application of the five lean thinking principles such as: flow, value stream, value, pull and perfection at the Department of Post Construction at Building Companies [8].

Table 1 Relationship between the objectives, principles and proposals for the application of lean tools.

Objectives	Five principles of lean construction	Proposals for the application of lean tools at the Post Construction Department in Construction Companies
-Creating working routine	Value	Rationalization of the stages on customer service
		Reduction of service time—lead time
		Work performed in parallel
		Perform quality services and on time
		Identify customer requirements through evaluations of customer's satisfaction with services provided at the end of the process
-Flowchart Mapping	Value stream	Mapping the value stream and routines that eliminate steps that add no value to the customer
		Creating a map of the flowchart steps that cause the most problems in the process
		To carry out preliminary inspections to verify the actual severity and the causes of the requests to assist in the sizing of the staff and equipment needed
		Forming partnerships with suppliers, so the delivery of materials could be done quicker
-Reducing waste	Flow	Creating work cell with multifunctional professionals
		To turn a workforce available to do the job without the interference of other departments, like other construction fields
		Creating the WI (work instruction) to the Post Construction Department
		Creating some indicators of productivity and time for assistance on solicitations
-To increase the transparence in the process	Pull	Takt time—Rhythm demand—It is necessary a solicitation by the client
		Propose a plan of periodic inspections within the guarantee period of five years after the release of the building or construction, in order to verify if the maintenance is being done, avoiding future solicitations or pathological manifestations
		Enabling the workforce to develop several tasks
-Eliminating some stages that do not increase value to the client	Perfection	The responsible for the management of the department will be an engineer or an architect
		Creating a structured Post Construction Department and self-manageable
		Training the workforce on the lean practice
		Effective communication
		Propose a more didactic manual's property and make speeches about the importance of building's maintenance in its lifetime
-Reducing time on assistance		Create a database that enables to include helpful information into the productive system, in order to avoid future failures
		Make periodical training with the building manager
		Make meetings with several facilities of the company, looking forward to exchange knowledge to seek continuous improvement on the processes
		Strategic compromise with the top management in application of lean tools

2. Methodology

According to the proposed objectives, this research paper is exploratory, because we seek a better understanding and improvement on methods of application of lean tools in the Post Construction Departments of Building Companies. The methodology used to make this project fits in action-research, considering that some researchers are involved in some of the companies that were part of the collected data.

On the first step, a literature review on the five principles of lean thinking such as value stream, value, flow, pull and perfection was done. Later on a connection was made between the research objectives, the five principles of lean thinking and lean tools that could be used within the Department of Post Construction of Building Companies.

On the second step, it was thought to conduct a study of several cases to acquire knowledge on how the Post Construction Department of the state's construction companies is developed in relation to lean practices. In order to get that, a semi-structured interview was developed with the responsible for the department of

each company. Five consolidated companies in the state's market were chosen, working on civil construction industry for vertical multifamily housing developments.

Among the participating companies, the Company Letter D is the only one which does not have a Post Construction Department formed, but due to the volume of works that have been delivered and are being implemented, the top management department noted the need to implement a Post Construction Department in a near future. The management support, the participation of a member from the technical group of employees were decisive for the companies to develop the guidelines for the department, which will support its implementation.

Some specific goals may also be listed, such as: align routine actions with strategic goals and map the process flow related to the use and maintenance of buildings, which may be a difference searching for strength and profitability of the companies [16].

As a way of supporting the objectives of this research, using the literature, some of the tools were selected within each principle of lean construction presented in Table 1. Developing lean tools adapted to the Post Construction Department of a Building Company like: analysis of the flowchart mapping and lead time activities, planned inspections and technical support form.

3. Data Collection

Semi-structured interviews were performed in each company, seeking to understand the organization of the Post Construction Department, its activities and its principles. The questions are presented below:

- Is there a Post Construction Department which carries out the technical assistance?
- How is the procedure for technical assistance since the customer until the delivery of the service conducted by the company? Can the company describe it?
- How is the assessment or refusing requests for customer service?
- Are there flow charts or work instructions that the company has adopted to standardize the technical assistance?
- Are staffs trained to perform these services? Is a qualified professional who performs the first inspection? Is this professional registered by CREA?
- What about the average time that the company spends to meet the maintenance demands of customers (for example, first contact with the client and schedule for completion of service)? How is the evaluation of delivery of the services performed?
- How are requests registered and monitored (tabulate and store)? Is there any way of tabulating these data to feed back into the production system for the next projects?
- How many projects does the company have built over the past five years and how it runs now?
- Does the company welcome the idea to develop a Post Construction Department as a preventive measure to post construction to meet future demands of its customers in a faster and better way?
- Is there an indicator developed in the Post Construction Department in a way to produce and control the services performed and the indicators for customer's satisfaction?

4. Data Analysis

The identification of business will be protected, each being assigned a company identification by means of letters (A, B, C, D). All the companies contacted were receptive to answering all the questions raised on the interviews. The directors of companies A, C and D participated in semi-structured interview to answer the questions in person, however, the responsible for Company B responded to questionnaire electronically.

Regarding to the existence of a Post Construction Department, Companies A, B and C stated that there is a Post Construction Department with some variation between them due to the volume of works to be met, however, Company D sees the need to create such a

department in the near future for its customers.

Regarding to the procedures of the companies A, B and C, they have operating procedures, by some called "OP (operating procedures)", by others "EPIS (Execution Procedure and Service Inspection)" or even "WI (Work Instructions)", the Company D is trying to develop its procedures. The Companys B and C mentioned that the disclosure of their documents is not a practice carried out by the company and therefore they could not turn their operating procedures available.

It is a common practice in all of the studied companies that all the customer requests made in by the customers must be made in hand writing or by telephone to the Technical Assistance Department of the Company. All the requests are usually received and the department contacts the costumer in order to schedule the date of the inspection, conducted jointly with an engineer or technician responsible for the department to register the occurrence and then proceed with the execution of the service, mobilization of material, equipment and labor work required.

It was observed within the interview that in some cases the first inspection in Company C is not performed by the engineer responsible for the Post Construction Department, but by someone encharged which is not recommended, due to the fact that the recording and analysis of the causes are not made by a formal technical knowledge. Both companys A and B confirmed that the first inspection of the customer's request is made by the engineer responsible for the department.

At the end of each Technical Assistance Service, the department conducts a quest with the client regarding to its services. In order to manage the technical assistance services in common areas, the engineer adopts the same procedure used for the units, but the building manager is responsible for requesting and tracking the services. In every company, except Company D, the Summary of Requests for Technical Assistance is presented in a technical meeting at the end of the month in order to discuss with all the stakeholders, trying to take corrective and preventive actions whenever it is necessary.

In the assessment related to the time required to meet the request, it was found that there are different times of attendance. The average time that companies use to make the first contact with the customer to provide feedback to a request for technical assistance and to schedule a technical visit takes 24 h to 48 h. Regarding to an implementation of a service, there is no accurate time required for completing the service, considering that there are variations due to the type of problem to be solved, ranging from one day to one week.

4.1 Flowchart Mapping and Lead Time of Activities

In Table 1, it can be observed that the flow mapping and elaboration of the mapping activities of the Post Construction Department can be framed in search for the attendance on the lean principle relating to the value stream and the attempt for reducing the lead time activities can be seen as a service to the lean principle related to the value. Fig. 1 shows how the activities of the Post Construction Department were identified and their respective estimated lead time. Fig. 2 represents the proposed activities for the Post Construction Department and the respective reduced lead time.

Reducing lead time at Post Construction Department was only possible with the implementation of a technical assistance (architect or engineer) which is in direct contact with the client, setting up an inspection directly technical/customer, and the preceding judgment by the technician, due to the fact that many times, this previous judgment could be done at the inspection. Beforehand, due to the fact that it was someone encharged to do the inspection, he or she did not have that authority and sometimes, he or she did not even have the appropriate knowledge.

After the solicitation judgment, the technical staff used to do the quantification of the technical staff, materials and schedule of the activities. The technician used to follow the inspection with the client and he or

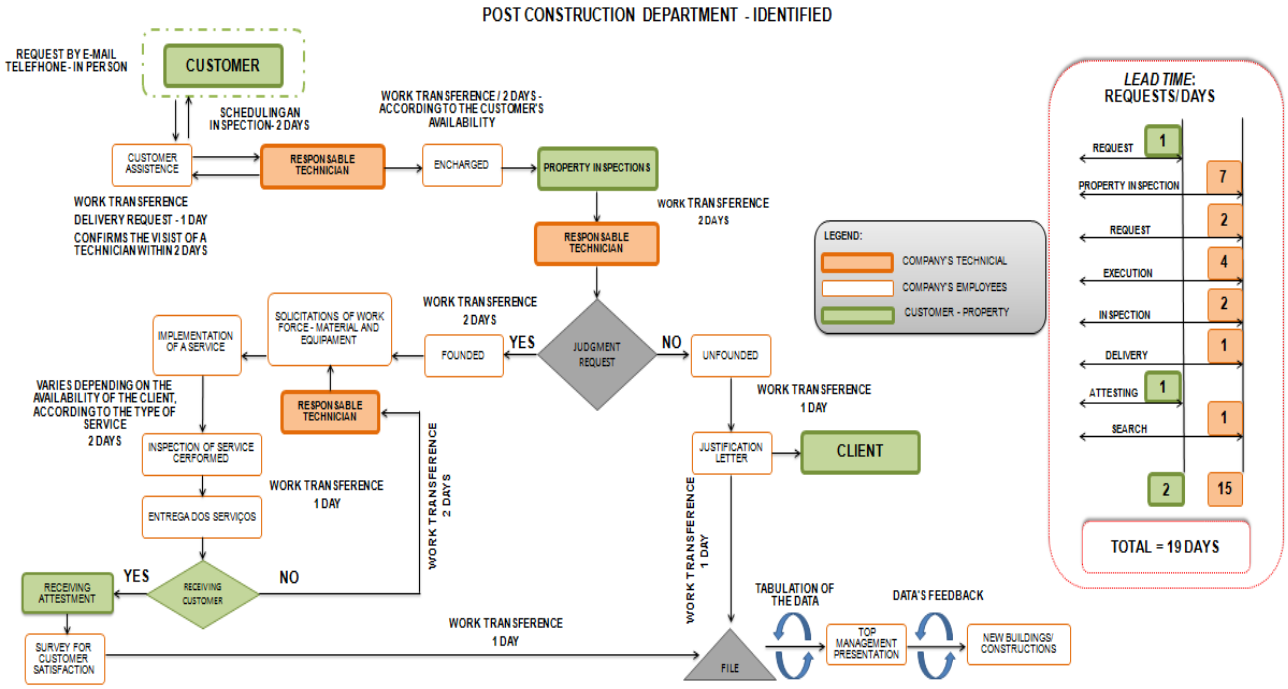

Fig. 1 Identified activities in the Post Construction Department and estimated lead time.

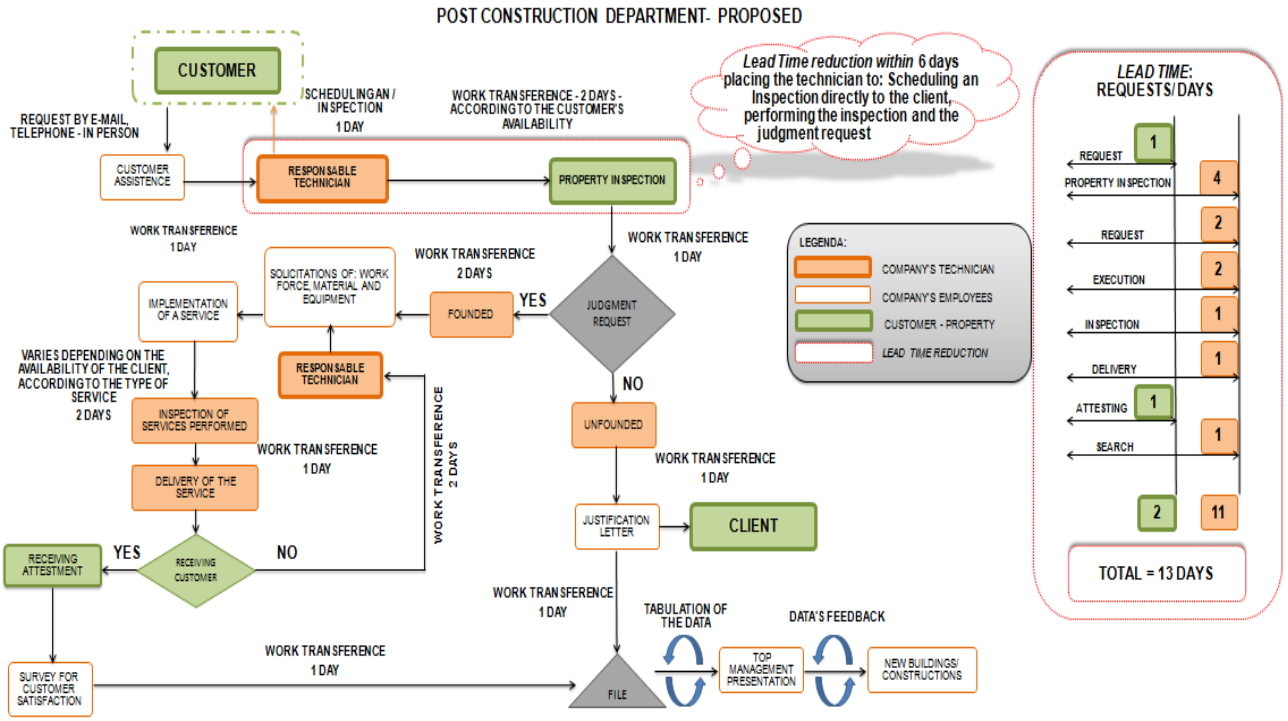

Fig. 2 Proposed activities for the Post construction Department and the reduced lead time.

she used to release the service to the client. This monitoring and final inspection before releasing the service to the customer, it was possible to detect problems within the implementation and future measures by the receiving client. It was found that the presence of a technician at all the stages helps to reduce the variability and a reduction of errors and delays in delivering services to the customer.

4.2 Planned Periodical Inspections

In order to propose a tool based on the lean principle referring to the pull concept, it is presented a way of planned intervention, based on preventive maintenance of buildings, in order to increase the useful life of buildings thus restoring a satisfactory level of performance for buildings. The implementation of these maintenance services may be offered by their own construction companies to the customers, via contract, so that the construction company can perform the services required guaranteeing the final product. In Table 2, an action plan is proposed with the frequency of preventive maintenance and inspections for building construction system that must occur from time to time in advance, from the release of the project.

4.3 Technical Assistance Request Form

The technical assistance request form aims at helping small and medium sized construction companies develop a Technical Service Department and to therefore meet the lean principle referring to perfection, seeking to standardize records, increasing transparency and the control of services. The use of this form will enable the company to register all customer's requests, to follow all stages of execution, register the costs regarding each request, register the team required for each type of activity, the engineer responsible for implementing each step, as well as the result of the customer satisfaction survey. In order to prepare the technical assistance request form, Microsoft Office Excel 2007 was used, along with Poka-Yoke concepts [17]. We have included a filled-in form (Fig. 3) in order to exemplify the use of the Technical Assistance Request form for plumbing installations.

Fig. 4 presents some results that can be obtained by the tabulation of some data's request in 2011.

5. Conclusions and Final Considerations

Participating companies proved to be aware and understand the importance of a Post Construction Department and its activities with the customers.

Among the difficulties found it is worth highlighting the measurement of average service time, considering that the lead time varies considerably depending on the type of activity that must be developed to meet the client's request.

The demand is another important key point for the analysis, because some companies do not have enough demand for services related to the request for technical assistance to maintain specific staff for the Post Construction Department. Faced with the discontinuity

Table 2 Periodicity of preventive maintenance and inspections.

Item	Constructive system	Time										Frequency of servicing
		6 months	1 year	1 year and a half	2 years	2 years and a half	3 years	3 years and a half	4 years	4 years and a half	5 years	
1	Concrete Structure		*		*		*		*		*	Every year
2	Metallic structure				*				*			Every 2 years
3	Waterproofing		*		*		*		*		*	Every year
4	Hydraulic Installation						*					Every 3 years
5	Sanitary wares and sanitary metals				*				*			Every 2 years
6	Electrical Installation		*		*		*		*		*	Every year
7	Wall coverings				*		*		*		*	Every 2 years
8	Inside and outside Painting		*		*		*		*		*	Every year
9	Covering system				*				*			Every 2 years
10	Glasses				*				*			Every 2 years
11		*	*	*	*	*	*	*	*	*	*	Every 6 months
12					*				*			Every 2 years

Microsoft Excel - OS - Assistência Técnica

LOGO	TECHNICAL ASSISTENCE FOR REQUEST FORM	SOS Nº	201101

1. Dados do cliente e ocorrência

Enterprise:	DIAMOND RESIDENTIAL	Block:	X
Address:	EMERALDS STREET	Apartment:	111
User:	DANIEL CUPERTINO DA CRUZ	Contact:	(062) 3333-5555
CPF:	333.444.555-66	RG:	2222244444
Profession:	CIVIL ENGINEER	Phone # (1st option)	(062) 5555-3333
E-mail:	FULANO@ASSISTÊNICA .COM.BR	Phone # (2st option)	(062) 6666-7777
Date of request:	15/11/2011	Time of request:	
Date the schedule:	17/11/2011	Note: 48 hours of the time limit date of request	
Starting date for executing the service:	21/11/2011	Note: 48 hours of the time limit date of schedule	
Expected date of completion of the service:	25/11/2011	Note: Estimated time for completion of service	
Date of completion for execution of the service:	24/11/2011	Note: Depend on the type of service to be held	
Date of receiving the service:	25/11/2011	Note: Date of receipt held by the user	

LEGEND: SEMAPHORE POKA-YOKE: Schedule, Reschedule, Delivery, Inspection, Replay, Search, Execution, Conclusion

OBSERVATIONS: Customer satisfaction in held after the service where the customer judges with notes 0 - 10 satisfaction

Item	Description of service / History of service	Condition Founded/Unfounded	Date	Situation	Semaphore POKA-YOKE	Responsabile for the step	Staff Available	Customer Satisfaction
1.0	Foundation							
2.0	Structure							
3.0	Electrical Installations / phones / cabling							
4.1	Realização da Vistoria	Founded	16/11/11	Inspection		Pedro	(2) Plumber ( ) Painter	9
4.2	Agendamento da execução do serviço - para data 21/11/2011		17/11/11	Schedule		Antônio	( ) Electrician ( ) Mason	
4.3	Execução do serviço - troca do sifão		21/11/11	Execution		Pedro	( ) Plasterer (1) Helper	
4.4	Conclusão do serviço		24/11/11	Conclusion		João	( ) Outsourced ( ) Others	
4.5	Entrega do serviço ao cliente		25/11/11	Delivery		João		
4.6	Pesquisa de satisfação do cliente		28/11/11	Search		Pedro		
4.0	Plumbing sanitary							
5.0	Special Facilities							
6.0	Masonry and Partitions							
7.0	Waterproofing							
8.0	Coverage							
9.0	Wooden frames							
10.0	Metal frames							
11.0	Glasses							

Plan1 Plan2 Plan3 Plan4 Plan5

Fig. 3 Filled form of technical assistance for hidro-sanitary installation.

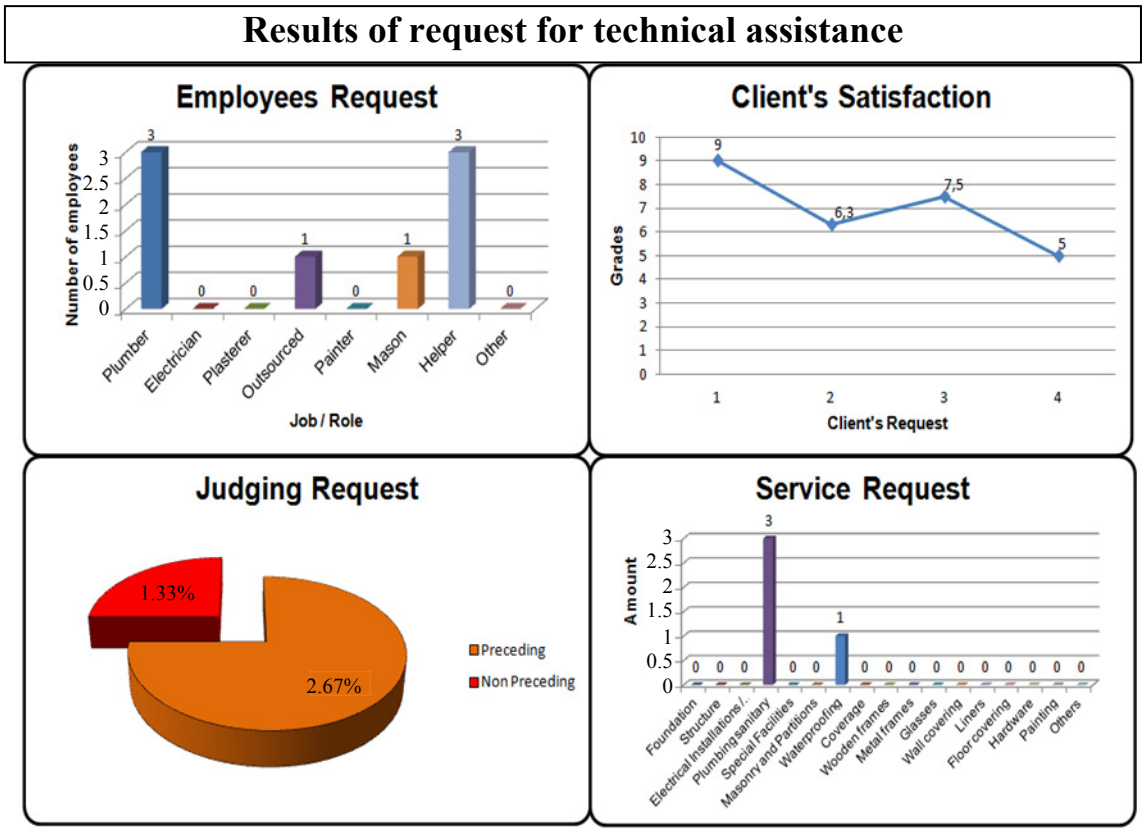

Fig. 4 Presentation of some tabulated results from technical solicitations.

of services employees are relocated to other service fronts and when necessary, they stop what they are doing to meet the request for technical assistance.

The discontinuity of production flows when removing an employee from construction works to carry out another service should be taken into consideration when planning activities since according to the lean principles, the continuous flow of activities must be met.

One way of compensating for this discontinuity would be a monthly analysis of requests in order to identify the services with higher demands and promoting appropriate training for employees so that they become multi-functional, as such specializing the workforce.

It was observed that there are many points that can be improved in the Post Construction Department with the lean tools, and the proposed operating procedures, technical request forms, flowchart mapping of activities, planning in the inspections in advance were some tools used on this research paper to demonstrate that it is possible to meet the lean principles: value, value stream, flow, pull, perfection, in the search for continuous improvement, transparency and processes' control.

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Sustainable Maintenance of Rural Roads in Slovakia

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Abstract: Systematic approach to the maintenance of rural road network is a very important issue from the viewpoint of public costs. Most countries developed custom PMS (pavement management systems) based on deterministic or probabilistic approach. The main goal is to ensure safety and continuity of road traffic on road network with low intensity and lower technical requirements. Article presents PMS used for Slovakia rural road network based on road construction diagnostics, traffic volume, climate factors and evaluation of maintenance works economics effectives by using of software tools like HDM-4 developed by World Bank. Local road administrators of rural road networks often lack the software equipment, most PMS, however effective, are often cumbersome, demanding in regard to energy, know-how and software equipment. The majority of local road administrators of rural road networks thus resort to non-effective reactive maintenance strategies. This article describes an easy to use method, based on predetermined maintenance repair and rehabilitation standards. A simple method, based on road user cost, is introduced that administrator can use to prepare a list of road section eligible for repair according to their repair priority.

Key words: Pavement management system, rural roads, maintenance repair and rehabilitation.

1. Introduction

Road administrators capabilities differ significantly in accordance with available budged, length of roads they are responsible for, demands put on their assets, demands put on acquisition of new assets and many other issues, yet their task is the same. Their task is to develop and maintain a safe, eco-friendly and efficient transport system.

1.1 Road Network of SR (Slovak Republic)

The road network of Slovakia consists of 391 km of limited access roads (motorways and express roads) and 174,367 km of 1st, 2nd and 3rd class roads. The main objective of motorway network is to provide transit according to Pan-European transport corridors, namely the IV, V and VI corridor. The purpose of express road network is to collect and transfer the transport generated by Slovak republic's regions and contra wise to distribute transport from foreign countries from motorways to the body of Slovak Republic. The 1st class trunk roads fulfill the service task of transportation between regions of Slovak Republic. 2nd and foremost 3rd class roads compose a rural road network. On top of this network, a network of urban communications and minor purpose communication is connected. Different types of roads have different owners and administrators with their executive offices. Their general task is to securing a fluent and safe transport on them entrusted roads by providing maintenance, winter service, repair, reconstructions and acquisition of new assets according to concept of development of road network of Slovakia.

This paper is aimed on the topic of road maintenance of low class road network (2nd and 3rd class roads) which constitutes the majority—three quarters—of the whole SR road network, as shown in Fig. 1, therefore the viewpoint of administrators of this road network will be crucial.

1.2 Sustainable Maintenance of a Road Network

The purpose of MR&R (maintenance repairs and rehabilitation) of asphalt pavements is to extend the useful life of the pavement, maintain a smooth riding

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surface and prevent water from entering the underlying soil. Limited manpower and resources have increased the importance of MR&R for the service life of a pavement. To keep a pavement in the best possible condition, it is important to use an effective pavement management system. Basic PMS logical structure is depicted in Fig. 2 [1].

Pavement management system is a subsystem of asset management. It should ensure an adequate dividing of assigned funds from state budget and additional regional tax funds [2]. These funds are very limited, thus, sustainability principles have to be implemented so that the road network can provide the road users with socio-economical benefits. These benefits elevate the living standards of the society, which, in turn, is then more prone to spending which means more taxation money. Previous sentence denotes that the relations form a cycle—sustainability cycle—which is depicted in Fig. 3.

From the economical viewpoint, the sustainability principle means to balance the spend funds with generated funds which again can be spend, and so on, in an infinite cycle.

2. Implementation of Sustainable Road Maintenance in Rural Road Network of Slovak Republic

At present, the ratio of 2nd and 3rd class roads in critical or poor condition and the amount of available resources of road administrators of this network is beginning to reach critical levels. While a thorough and effective road asset management even of motorways and 1st class roads is still far from completion a substitution solution which have to be made to help road administrators of lower class roads. Since the rural roads are not surveyed systematically and their condition is not being tracked and used as an input for PMS, the municipal administrators of these roads rely on fixed MR&R standard. The MR&R procedures prescribed by fixed maintenance standard do not always correspond with the actual needs of the road conditions, nor do they take into account the budget possibilities of the road administrator, it is merely an empirically based schedule of pavement treatment works, which guarantees a good condition of the road throughout its whole life cycle. The downsides are obvious, the overall idea does not (mainly a high cost of this standard) correspond with the procedures described in asset management theory. Thus, road administration does not work effectively. Therefore, a search for lower-cost maintenance standards and the process of assigning them to individual rural roads started as a part of research on University of Žilina. The aim is to assess the possibilities

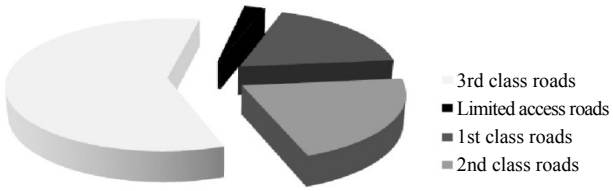

Fig. 1 Composition of road network of Slovak Republic.

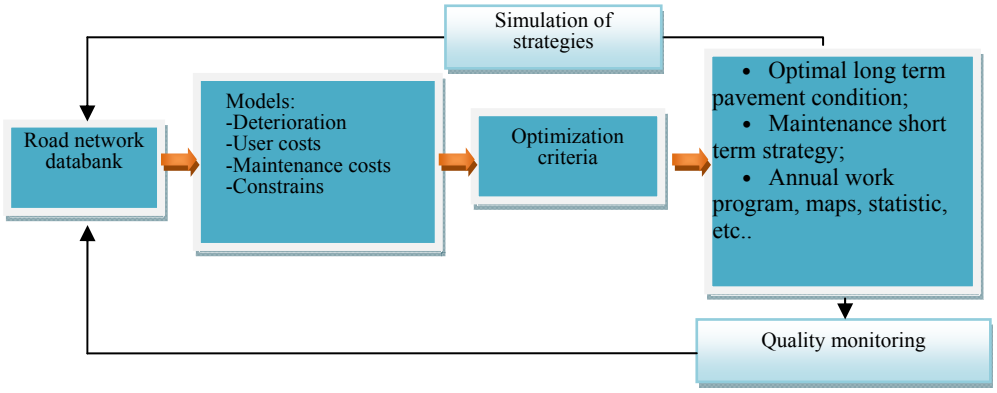

Fig. 2 Basic PMS scheme.

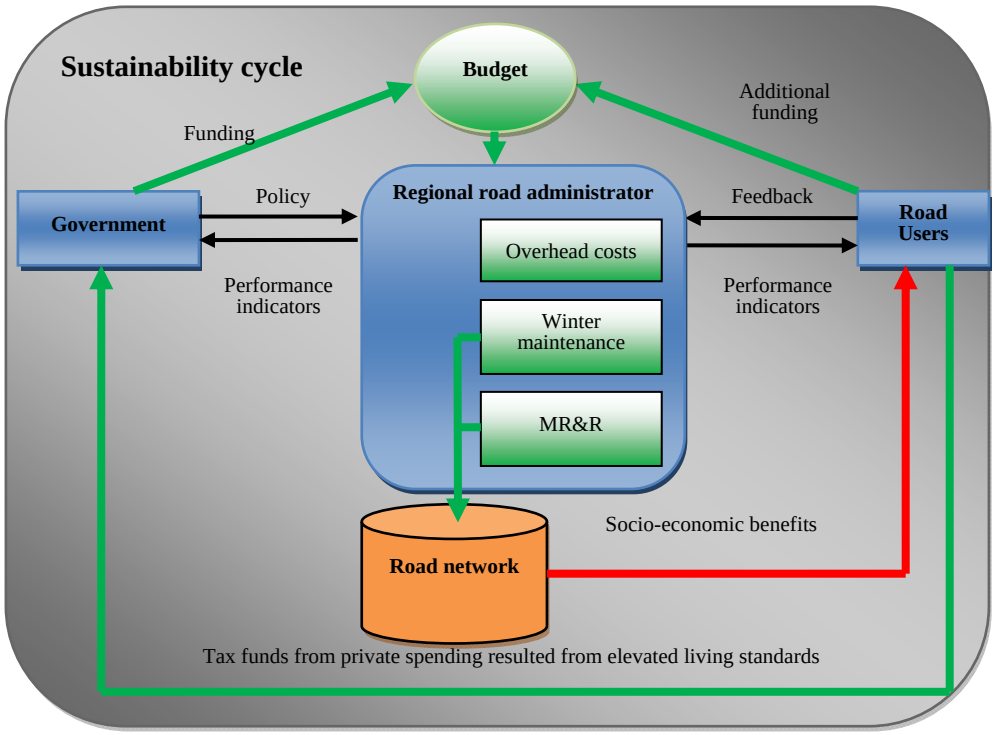

Fig. 3 Principle of sustainability in road administration

of cheaper maintenance while ensuring fair pavement quality to the society. This also means that instead of having part of road network maintained in sub-optimal and part in over-optimal condition, more homogenous ride quality on whole network will be achieved.

2.1 The Previous Results

In the last part of research [3] at our department, we have assessed the suitability of lower-cost maintenance standards for rural road network.

The condition of pavement related to service life for different variants is shown in Fig. 4. Variant 1—v1—is not shown in this picture, as the variant itself is responsive and not fixed. Fig. 5 shows the costs of different variants.

The results in Fig. 5 show five alternate MR&R variants, each with different cost and effects on pavement conditions. The variants are ranked for cost, technical suitability, economic effectiveness and from overall point of view. Following conclusion was drawn from this research:

Variant 1: current maintenance variant—very expensive variant appropriate only for road sections with heavy traffic load;

Variant 2: microsurfacing based variant—safe to use on all rural roads;

Variant 3: balanced cover layer exchange based variant—may be appropriate even for 3rd class roads with traffic load under 1000 AADT (annual average daily traffic) especially, if they are not subject to excessive high load vehicles encumbrance;

Variant 4: one major cover layer exchange based variant—fairly safe to use on all rural roads.

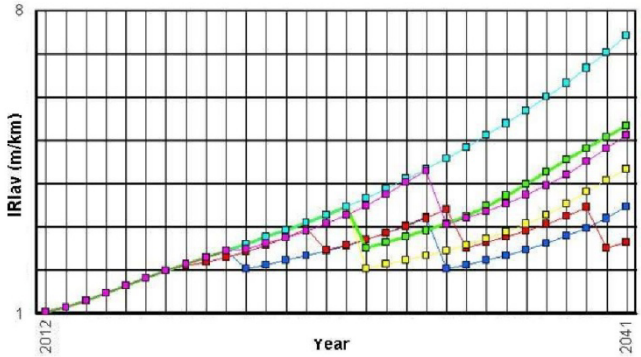

Fig. 4 Pavement condition expressed by IRI (international roughness index) for different MR&R variants.

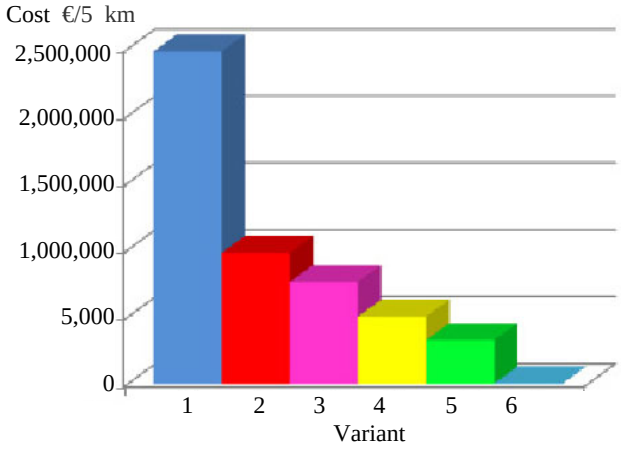

Fig. 5 Costs of different MR&R variants.

Variant 5: one microsurface based variant—may be appropriate even for 3rd class roads with traffic load under 1000 AADT especially if they are not subject to excessive high load vehicles encumbrance.

Variant 6: basic variant—is appropriate only for 3rd class roads where the 1000 AADT limit is not exceed and are not subject to excessive high load vehicles encumbrance.

2.2 Next Steps

The road network is inhomogeneous and dynamic environment. The traffic load, condition of particular road section, volume of maintenance on this section in contrast to road administrator capabilities and others factors, all play an important part for choosing the appropriate MR&R standard. Ranking of variant as seen in Table 1 is appropriate, however, use of a more in-depth multi-criteria analysis is advised. A sound method which can be used for multicriteria analysis based on third party programs like HDM-4 may be derived from Ref. [4].

In an ideal case, road administrators would use analytical software to estimate which MR&R standard should be used to maximize the socio-economic benefits for road users. For now, a complementary and easier method must be used. The method should enable road administrators to quickly calculate socio-economic benefits for one vehicle, which, when combined with traffic survey, would enable them to calculate socio-economic benefits for the whole road section. Note, that regional road administrators would have to implement a basic road condition survey system as some pavement data will be the input for such a system.

3. Sustainable Pavement Maintenance Solutions for Regional Road Administrators

As we know, there are several factors influencing economical effectiveness of road maintenance and repair works, it is mainly the difference between technical parameters of maintained (do something) and un-maintained (do nothing) road, and costs of these works. Since MR&R works do not influence the fixed technical parameters like geometrical alignments or width of communication, it is the surfacing parameters which changes are generating the benefits. It is assumed, that the main pavement condition parameter is the IRI (international roughness index) which usually is the main indicator of road surface condition [5]. To prove this assumption we did an experiment in HDM-4—to show the influence IRI has on vehicle operating speed which change is the main indicator of road user benefits. Subsequently, we transformed known mathematical equations used to calculate operating speed in relation to IRI to better suit the environment of rural road network of Slovak Republic.

IRI as a factors influencing operating speed of

Table 1 Rankings of MR&R variants.

Viewpoint	Variant 1	Variant 2	Variant 3	Variant 4	Variant 5	Variant 6
Cost	6th	5th	4th	3rd	2nd	1st
Technical suitability	1st	2nd	5th	3rd	4th	6th
Economic effectiveness	4th	5th	3rd	2nd	1st	6th
Overall	3rd	4th	5th	1st	2nd	6th

Table 2 Vehicle operating speed (km/h) depending on IRI.

Conditions	Car category	Environment	IRI											
			1	2	3	4	5	6	7	8	9	10	11	12
Straight and level alignment with low intensity	Personal car	Non-urban	94.2	94.1	94	93.4	91.7	87.6	81.2	73.8	66.8	60.6	55.3	50.8
		Urban	54	54	54	54	53.9	53.9	53.7	53.2	52.4	51.1	49.3	47.1
	Lorrie	Non-urban	86.2	86.1	86	85.7	84.7	81.3	74.6	66.9	60	54.1	49.3	45.2
		Urban	54	54	54	54	54	53.9	53.8	53.3	52.2	50.1	47.4	44.3
Curvy alignment with low intensity	Personal car	Non-urban	93.5	93.4	93.2	92.7	91	87.1	80.9	73.7	66.7	60.6	55.3	50.8
		Urban	54	54	54	54	53.9	53.8	53.6	53.2	52.4	51.1	49.3	47.1
	Lorrie	Non-urban	84.7	84.6	84.4	84.2	83.3	80.2	74.1	66.7	59.9	54.1	49.3	45.2
		Urban	54	54	54	54	54	53.9	53.8	53.3	52.1	45.2	47.4	44.3
Curvy alignment with high intensity	Personal car	Non-urban	93.5	93.4	93.2	92.7	91	87.1	80.8	73.6	66.7	60.6	55.3	50.8
		Urban	54	54	54	54	53.9	53.8	53.6	53.2	52.4	51.1	49.3	47.1
	Lorrie	Non-urban	84.7	84.6	84.4	84.2	83.3	80.2	74.1	66.7	59.9	54.1	49.2	45.2
		Urban	54	54	94	54	54	53.9	53.8	53.3	52.1	50.1	47.3	44.3

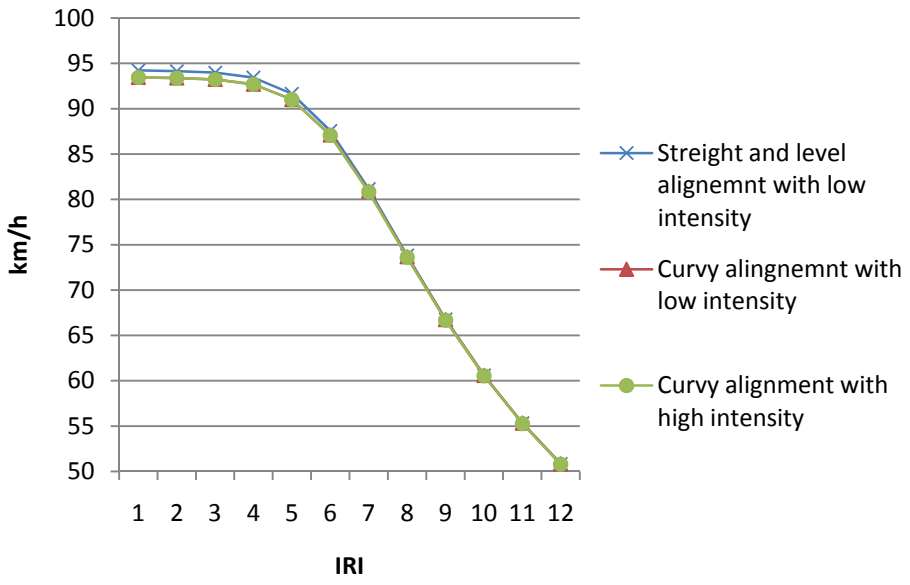

Fig. 6 Vehicle operating speed in relation to IRI.

vehicles, for this experiment, first, a straight and level road section was created. Very low traffic intensity (1,000 AADT) was set and the operating speed was calculated for different IRI ranging from 1 to 12 on this road. Subsequently, the test was performed both in urban and un-urban environment for private cars and lorries.

As an alternative, a geometrically tortuous variation of this road was made (resembling a typical alignment for rural road section in SR environment). This way, we could examine the speed difference between two different alignments to estimate the impact of curvature of the road. The third run raised the low 1,000 AADT traffic intensity to a high 10,000 AADT.

The results shown in Fig. 5 denote that on a typical rural road, neither the alignment, nor intensity plays a marginal role in vehicle speed reduction. The mayor difference pertains to IRI. The full results are shown in tabular format in Table 2.

With the result in mind, we have derived a conclusion that a road administrator of a rural road network is capable to assess the importance of MR&R action by a simple calculation where the IRI and traffic intensity of are the sole inputs for calculation of MR&R action efficiency. He would not be able to calculate user cost directly, but he can collate road sections under his administrations and make a schedule of works with top priority MR&R actions being on top. Using Table 2 and Eq. (1), he can calculate PI (prioritization index).

$$PI = AADT \cdot (VOS_{BA} - VOS_{AA}) \quad (1)$$

where,

PI prioritization index;

VOS_{BA} vehicle operating speed before action;

VOS_{AA} vehicle operating speed after action.

Table 2 shows the impact of IRI on vehicle operating speed traveling on respective type of a road. Graphical representation of these results is shown in chart depicted in Fig. 6. Higher PI denotes a more effective MR&R action. Provided we assume that vehicle operating speed is the main indicator of road user costs, the PI is proportional to user cost savings. Two main factors are neglected in this approach—the cost of MR&R action and length of a road section. The premise is that length ads cost as well as benefits. This is a coarse statement but valid for road sections with length of about 0.2-5 km.

This sound and easy method may be used as a basic decision making tool. Administrator still has to select technologically correct MR&R technology, but it is a step to a proactive pavement management strategy.

4. Conclusions

The sustainability of rural road network requires an easy to use decision making method for regional road administrators of this road network. Method described in this is easy to implement and adapt. Only minor calibrations are needed for application:

(1) MR&R standards should be identified by a national road administration body as this step is too elaborate for a local administrator to do;

(2) The ranking of these variants is best to be performed by national transport research institution of a respective country.

Local road administrator is also advised to apply this method on a limited part of road network within his whole road matrix and assess the results before a full-scale implementation.

Acknowledgments

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A Comparative Analysis of Owner-Contractor Agreements in the Turkish and US Construction Industry

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Abstract: Successful and cost-effective construction relies upon appropriate communication of the participants of the construction project. Hence, it is important to define the rights and responsibilities of the parties, and relationships among them. In this context, well-designed and complete agreement is essential and necessary for the successfully completion of a construction project within the desired time, quality and budget. In this paper, it is aimed to analyze and compare the owner-contractor agreements in the Turkish and the US construction industry. First, the importance of construction contracts and contractual elements of an agreement is determined, and then, the standard owner-contractor agreement which is used in the Turkish construction industry is analyzed and compared with the US standard owner-contractor agreement. Finally, the differences between these agreements are put forward, the lack and deficiencies of Turkish standard agreement form are determined, and appropriate suggestions are improved.

Key words: AIA (American Institute of Architects), construction contracts, KIK (Kamu Ihale Kurumu), owner-contractor agreement, standard forms.

1. Introduction

The usual construction contract consists of a number of different documents. In order for the work to be completely defined, the contract must be accompanied by a number of other documents that (for the sake of convenience and propriety) are prepared separately from the body of the contract [1]. This collection of documents is known as contract documents. Contract documents play an important role in the development of a project and provide the bridge between the owner's conceptual image of a project and the actual construction of the physical facility [2]. All the contract documents are important for successfully completion of a construction project, but the agreement is a vital one as it defines the relationships and obligations between owner and contractor and constitutes basic principles and procedures of the contract.

This paper aims to analyze and compare the owner-contractor agreements in the Turkish and the US construction industry. In order to reach this aim, first, the construction contracts are clarified, and then, the agreement and its contractual elements are explained. Next, US AIA (American Institute of Architects) standard contract forms and Turkish KIK (Kamu Ihale Kurumu) standard forms are represented. Of these documents, the owner-contractor agreement forms are selected for the comparative analysis. In this context, first, AIA Document A101-2007 Standard Form of Agreement between Owner and Contractor is compared with the KIK Standard Contract for Construction Works. Finally, the main differences between these agreements are put forward, the lack and deficiencies of Turkish standard agreement forms are determined, and appropriate suggestions are improved.

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2. Construction Contracts

A contract is a legal agreement between two or more parties that agree to be bound in a relationship. These parties are bound to each other for a certain period of time by a unique and exclusive relationship they have created for their mutual benefit [3]. Although there are many types of construction contracts, they can be divided into two main groups, based on the number of contracts (such as single-prime and multiple-prime contracts) and method of payment to the contractor (such as lump sum, unit price and cost-plus,).

In terms of the number of contracts, usually an owner initiates a single-prime construction contract or multiple-prime contracts. A single-prime contract is a common form of construction contracting. In single-prime contracts, the owner and contractor enter into a contract formalizing their relationship and their obligations. Besides, in a multiple-prime construction contract, the work is divided among several contractors, and the owner enters into a separate contract with each contractor.

Construction contracts also differ based on the method of payment to the contractor. First of all is the lump sum contract, which is the most popular fixed price contract, where the total price of the project is estimated at the bidding stages [2]. In this type of contract, there is an agreed amount for a described extent of work, based upon complete or partially complete construction documents. Lump-sum contracts are preferred when the scope of the project is well defined with predictable costs and low implementation risks [3]. The second one is unit price contracts, which are based on the unit price for each parties of the construction. In this type of contract, payment is made at a stipulated rate multiplied by the quantity completed. Unit prices are used in cases where the exact extent or quantity of work cannot be calculated accurately or determined in advance of actually performing the work. The decision whether to choose working with unit price contract depends on the amount of risk which is inversely proportional to the indefiniteness of the available information [3]. Another contract is cost-plus-fee contracts, which are derived either by adding a pre-established percentage mark-up to each item in the schedule, or by applying a fixed pre-determined fee for overhead and profit [1]. In a cost plus fixed fee contract, the owner and contractor agree on the fee that covers the profit and expenses of the contractor when drafting the contract [2]. Various types of cost-plus-fee contracts are cost plus percentage, cost-plus-fixed fee, cost-plus incentive fee and maximum cost-plus-fee contracts. The last one is the guaranteed maximum price contact, which is agreed upon maximum contract sum not to be exceeded. In this type of contract, the contractor guarantees that the project will be constructed in full accordance with the drawings and specifications and the cost to the owner will not exceed some total upset price [4]. Furthermore, the owner has a possibility of reducing costs and the contractor has a chance to increase his profit.

Depending on the project delivery, the number of contracts, and the basis of payment, a specific form of agreement will be required which will state the relationships and obligations of the signing parties for the variations involved.

2.1 The Agreement

Although often referred to as the contract, the construction agreement is only one of the various documents that make up the contract documents which specifically designed to formalize the construction contract and legally obligates the signing parties. The key component for the contract for construction is the agreement between owner and contractor. The agreement defines the relationships and obligations between owner and contractor and acts as a single instrument that serves the purpose of presenting a condensation of the contract elements, stating the work to be done and the price to be paid for it, and provides suitable spaces for the signatures of

the parties [4].

According to the Construction Specification Institute [5], the owner-contractor agreement typically includes articles relating to the following: (1) contract documents: a detailed list of all written and graphic documents that are part of the contract; (2) contract time: start and completion dates or allotted calendar days for the project; (3) contract price: the basis on which applications for payment will be made, and includes the listing of any unit prices, allowances and accepted alternates; (4) payment procedures: identifies when the contractor will submit applications for payment and when payment by the owner to the contractor will be made.

In order for the work to be completely defined, the agreement incorporates all of the other documents that make up the contract documents: contracting forms; project forms; conditions of the contract (general and supplementary conditions); specifications; contract drawings; and revisions (addenda), clarifications and modifications [5]. Of these documents, the agreement and the conditions of the contract have been developed by professional associations into standard forms.

2.2 Standard Agreement Forms

Several professional associations and government authorities have developed various standard agreement forms. This standardization of agreement forms has several advantages such as saving preparation time, proposing a complete and accurate document and eliminating disagreement areas between the contracting parties. Through repeated use, forms with standardized clauses have become well understood by owners, architects/engineers, suppliers, and contractors and are less subject to misinterpretation [5]. In addition, they have withstood the test of time and experience and have become familiar to architects/engineers and contractors who clearly understand their meanings and implications [4].

Standardized versions of several agreement forms have been developed by various professional, business and public organizations. Some of these professional associations which develop standard agreement forms in the United States are the AIA (American Institute of Architects), the AGC (Associated General Contractors) of America, the EJCDC (Engineers Joint Contract Documents Committee), and the DBIA (Design-Build Institute of America). Several different standard agreement forms have been published by these associations for the various project delivery methods and basis of payments. As AIA documents are referred to the most widely used standard forms [3], AIA standard agreement forms are preferred to make the comparative analysis.

2.3 AIA Standard Agreement Forms

The AIA was founded in the US in 1857, has been the leading professional membership association that represents member architects and related professionals. The main approach of this association is to promote the scientific and practical perfection of its members and to elevate the standing of the profession [6]. In this regard, AIA publishes standard contract forms for the design and construction industry in order to manage the relationships involved in construction projects.

AIA organizes its standard contract forms into two main groups and the classification of documents can be seen in Table 1. The first group is AIA series, which is based on the use of the document and the parties of the agreement. The second one is AIA families, which is based on the types of projects or particular project delivery methods.

As this paper is concentrated on the owner-contractor agreements, it is important to explain AIA's A Series. A Series include standard forms related to owner-contractor agreements. In A Series, there are 27 different standard forms. Of these standard forms, there are six types of owner-contractor agreements for different project delivery systems, payment methods and project types.

Table 1 Classification of AIA contract forms.

AIA series	AIA families
A Series: Owner/contractor agreements B Series: Owner/architect agreements C Series: Other agreements D Series: Miscellaneous documents E Series: Exhibits G Series: Contract administration and project management forms	Conventional (A201) family CMA (construction manager as adviser) family CMC (construction manager as constructor) family Design-build family IPD (integrated project delivery) family Interiors family International family Small projects family

Moreover, there are eight more owner related agreement forms for different participants such as construction manager, design-builder, vendor and subcontractor. A Series also includes general conditions of the contract for construction, guide for supplementary conditions, instruction to bidders and bonds.

As this paper deals with the owner-contractor agreements, AIA Document A101-2007 standard form of Agreement between owner and contractor is selected for the comparative analysis.

A101 is intended for use on construction projects where the basis of payment is a stipulated sum (fixed price). It is suitable for any arrangement between the owner and contractor where the cost has been set in advance, either by bidding or by negotiation [7]. A101 has 10 main articles which are: (1) the contract documents; (2) the work of this contract; (3) date of commencement and substantial completion; (4) contract sum; (5) payments; (6) dispute resolution; (7) termination or suspension; (8) miscellaneous provisions; (9) enumeration of contract documents; (10) insurance and bonds.

2.4 KIK Standard Agreement Forms

In Turkey, the only association which publishes standard contract forms is a governmental authority, Public Procurement Authority (KIK). The standard contract forms are government contracts which are developed based on the Turkish Public Procurement Law No. 4734 [8]. Although the construction project participants are free to use any standard contract forms in their private construction works, KIK standard contract forms are compulsory for the public construction works in Turkey.

KIK has two different contract document groups related to construction projects. The first group is for construction works procurements, and the second one is for consultancy services procurements. The classification of KIK contract documents is given in Table 2.

Unlike AIA, KIK has one and only standard form for owner-contractor agreements. The standard form of agreement between owner and contractor is named as SCCW (standard contract for construction works). SCCW has 35 main articles consist of provisions about the parties, contract type and price, bonds, payments, etc. [9]. This owner-contractor agreement is used with each project delivery system and payment methods.

3. Comparative Analysis of Owner-Contractor Agreements

Following table compares the standard form of agreement of AIA/A101 and KIK/SCCW in terms of the basic articles they are composed of. To compare the two agreement documents: Firstly, AIA/A101 form's basic articles are expanded; Then, it is searched that whether the KIK/SCCW agreement has corresponding provisions or not. As shown in Table 3, the corresponding provisions are given in the related rows. Besides, provisions that are not found are marked with an asterisk (*).

In Table 3, A101's 10 main articles with their own sub-articles are listed. Likewise, SCCW's corresponding provisions are given in the related next column.

Table 2 Classification of KIK contract forms.

Construction works procurements	Consultancy services procurements
Standard contract for construction works	
General specifications for construction works	Standard contract for consultancy services
Standard administrative specification for the works procurements	Standard administrative specification for consultancy services
Standard prequalification specification for the works procurements through the restricted tender procedure	Standard prequalification specification for consultancy services

It is seen that SCCW does not correspond AIA's many articles. Even, when the contents of the articles are deeply analyzed, it is seen that SCCW has several lacks when compared to A101.

These lacks are specifically shown in the provisions about the third parties, contract documents, contract sum, payments and dispute resolution.

One of the most important lacks in SCCW is that, there is no provision about the identification of the third parties. However, A101 identify the architect as a third party and has given the contract administration duties and responsibilities to the architect as the owner's representative. Although the architect is not one of the signing parties, A101 gives the necessary information about the architect in its cover page. SCCW does not deal with any representatives and does not give any clue about the contract administration. On the other hand, the owner and contractor can also have their own representatives and their information is given in the miscellaneous provisions.

In A101, a list of contract documents is given in Article 1 and the details of each contract document are explained in Article 9. According to A101, contract documents consist of the agreement, conditions of the contract (general, supplementary and other conditions), drawings, specifications, addenda (issued prior to execution of the agreement), other documents listed in the agreement and modifications (issued after execution of the agreement). A101 gives priority to no particular contract document; each contract document has equal importance. SCCW also has provisions about contract documents but unlike A101, it has a statement concerning the relative priority of the contract documents among them. SCCW gives a list of contract documents by giving no explanations about them. According to their priorities, contract documents are: general conditions, administrative conditions, draft agreement, drawings, location lists, special technical specifications, general technical specifications, clarifications (if any) and other annexes.

Another difference is about the provisions related to the contract sum. A101 in its Article 4, allows the owner to decrease the cost by changing some construction items or identifying alternates. New unit prices can also be identified and adjustments can be made in the contract sum. However, SCCW does not allow any changes and there are no provisions about adjustments in the contract sum.

The progress payment procedure is also different in both agreements. As it is shown in Fig. 1, in A101, the contractor applies to the architect for the progress payments. After the architect's evaluation, the owner makes the payment to the contractor. The time of the progress payments is also indicated in the related space in Article 5. On the other hand, in SCCW, the contractor directly applies to the owner for the progress payments. After the evaluation within 30 days, the payment is made in 15 days.

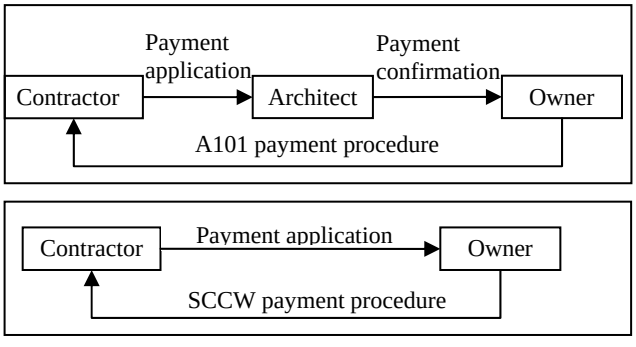

Fig. 1 Progress payment procedures.

Table 3 Comparison of AIA/A101 and KIK/SCCW agreements.

AIA/A101	KIK/SCCW	AIA/A101	KIK/SCCW
Cover page	*	A.5 Payments	A.11 Place and terms of payment
1. Date	A.34 Enforcement	5.1 Progress payments	
2. Owner	A.1 Parties to the contract A.2 Information about the parties	5.2 Final payment	
3. Contractor		A.6 Dispute resolution	A.31 Settlement of disputes
3. Project	A.3 Name, location, nature, type and amount of work	6.1 Initial decision maker	*
4. Architect	*	6.2 Binding dispute resolution	*
A.1 The contract documents	A.8 Annexes to the contract	A.7 Termination or suspension	A.26 Terms of termination of contract
A.2 The work of this contract	*	7.1 Termination	
A.3 Date of commencement and substantial completion	A.9 Date of commencement and completion of work and penalties applicable for delays	7.2 Suspension	A.27 Increased works, decreased works and dissolution works under contract
3.1 The date of commencement of the work		A.8 Miscellaneous provisions	A.32 Miscellaneous provisions
3.2 The contract time		8.1 Reference	*
3.3 Substantial completion		8.2 Interest rate	
A.4 Contract sum	A.6 Contract type and price	8.3 The owner's representative	
4.1 The contract sum		8.4 The contractor's representative	
4.2 Alternates	*	8.5 Change of representatives	
4.3 Unit prices		8.6 Other provisions	
4.4 Allowances		A.9 Enumeration of contract documents	A.8 Annexes to the contract
		A.10 Insurance and bonds	A.17 Protecting and insuring the work and worksite

Another important lack of SCCW is about dispute resolution. In A101's Article 6, the owner and contractor may identify an initial decision maker to render initial decisions on claims arising between them. If the parties do not identify an initial decision maker, then the architect will provide initial decisions. Besides, the parties can select from three choices of binding dispute resolution such as arbitration, litigation or another method that the parties identify [7]. However, SCCW does not present and allow any dispute resolution method. SCCW indicates that the disputes that may arise between the parties during the execution of the contract shall be settled by the Turkish courts.

4. Conclusions

This paper analyzed the Turkish standard owner-contractor agreement (KIK/SCCW) in by comparing it with the US agreement (AIA/A101). When compared with A101, it is found that some important provisions are missing in SCCW. These missing provisions are shown in the important contractual elements such as identification of the third parties, contract documents, contract sum, payments and dispute resolution. Due to the lack of these elements, the agreement is not sufficient, comprehensive and useful both in scope and content.

When SCCW is analyzed, it can be seen that, there is a need of a new series of owner-contractor agreements which provides a wide range of forms to meet the various and diverse needs different project delivery systems and payment methods. One type agreement cannot be appropriate for all the project types and payment methods. Besides, the agreement has to be accompanied by other contract documents and required explanations have to be given within the agreement.

Although the owner and contractor are the only

signing parties of the agreement, a third party is required for the contract administration. SCCW has to add necessary provisions about contract administration and assign a representative to fulfill these administration duties and responsibilities.

Because of the nature of the construction itself, there can be a need of making modifications or additions to the statements in the agreement. However, it is impossible to make changes in SCCW, especially, in the contract sum, construction items and unit prices. SCCW needs to be revised in order to allow changes and adjustments.

Another important problem in SCCW is the lack of a mechanism about dispute resolution procedure. If any dispute arises between the parties, SCCW should propose an alternative dispute resolution mechanism such as mediation or arbitration as they avoid the increasing caseload of traditional courts.

To conclude, the agreement plays vital roles in order to successfully complete of the construction projects within the desired goals. Due to the lack of some important contractual elements, problems are inevitable between the parties. Therefore, new and comprehensive series of owner-contractor agreement with revised provisions is required for the successfully completion of the construction projects in the Turkish construction industry.

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Tourism as an Industry in Heritage Site—A Case Study on World Heritage Site of Fujian Tulou

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Abstract: Cultural heritage is seen as a cultural capital. The heritage tourism increases the local employment and income, however, brings some problems at the same time, changing the traditional living way and industrial structure. The sustainability of economic development by tourism is also questioned. Fujian Tulou is a world heritage site in China, inscribed in 2008. The nomination has brought great changes to the sites, especially the flourishing tourism industries by the local communities as well as the tourism companies. The latter also take part in the management of the heritage site and get most of the income. The data in economic areas is analyzed in this study and explains the cultural tourism as a positive drive for the local economy, which contributes little to the life of locals. With the analysis of the changes and benefits from the tourism, we have found that tourism, as a dominant industry, might be a potential negative element for heritage conservation. According to the different situations of sites in Fujian Tulou, a proper planning of management is in need to integrate the tourism, conservation and development.

Key words: Tourism, industry, cultural heritage conservation, Fujian Tulou.

1. Introduction

Fujian Tulou is a world heritage site in China. Tulou means “earthen house” in Chinese, and it is a kind of vernacular architecture in southeastern China, especially in Fujian Province. Fujian Tulou is a particular type of communal living and defensive organization, known as “a little kingdom for the family” or “a bustling small city”, which houses up to 800 people in one building.

The nominated buildings (Tulous) are located in ten villages or towns of three separate counties, belonging to two cities (Fig. 1). They are constituted of 46 buildings, of which some are single buildings while others are in clusters (Table 1). These houses were constructed between 15th to 20th century, of which four buildings were constructed in Ming dynasty (AD 1368-1644), 24 in Qing dynasty (AD 1644-1912), seven in Republic of China (1912-1949) and 11 after 1949 (Fig. 2). They were built by the Hakkas to defend their enemy, combined with the building traditions of the indigenous [1]. Tulous are of multi-story structure and inward-looking. Each building was built to house a large family, each core family of which lives in a vertical unit of the house. With the growth of population, this large family might build another Tulou, so built the relation of mother and son between these two houses.

The floor plan of Fujian Tulou is circular or square. The circular buildings are seen as a mature style which remedies the defects in structure of square buildings. Tulou could also be classified by the form of interior space. In some buildings, each core family has their own entrance and stair, while others share their transportation space with corridors linking all the household (Fig. 3). In the courtyard of the building, there might be some public buildings for all the residents, such as the ancestral hall, the school or the salon. Tulou and its environment function as the living, working and amusing places for the residents.

Fujian Tulou is not only an exceptional example of unique building traditions but also a living heritage interprets the local community culture. It presents a

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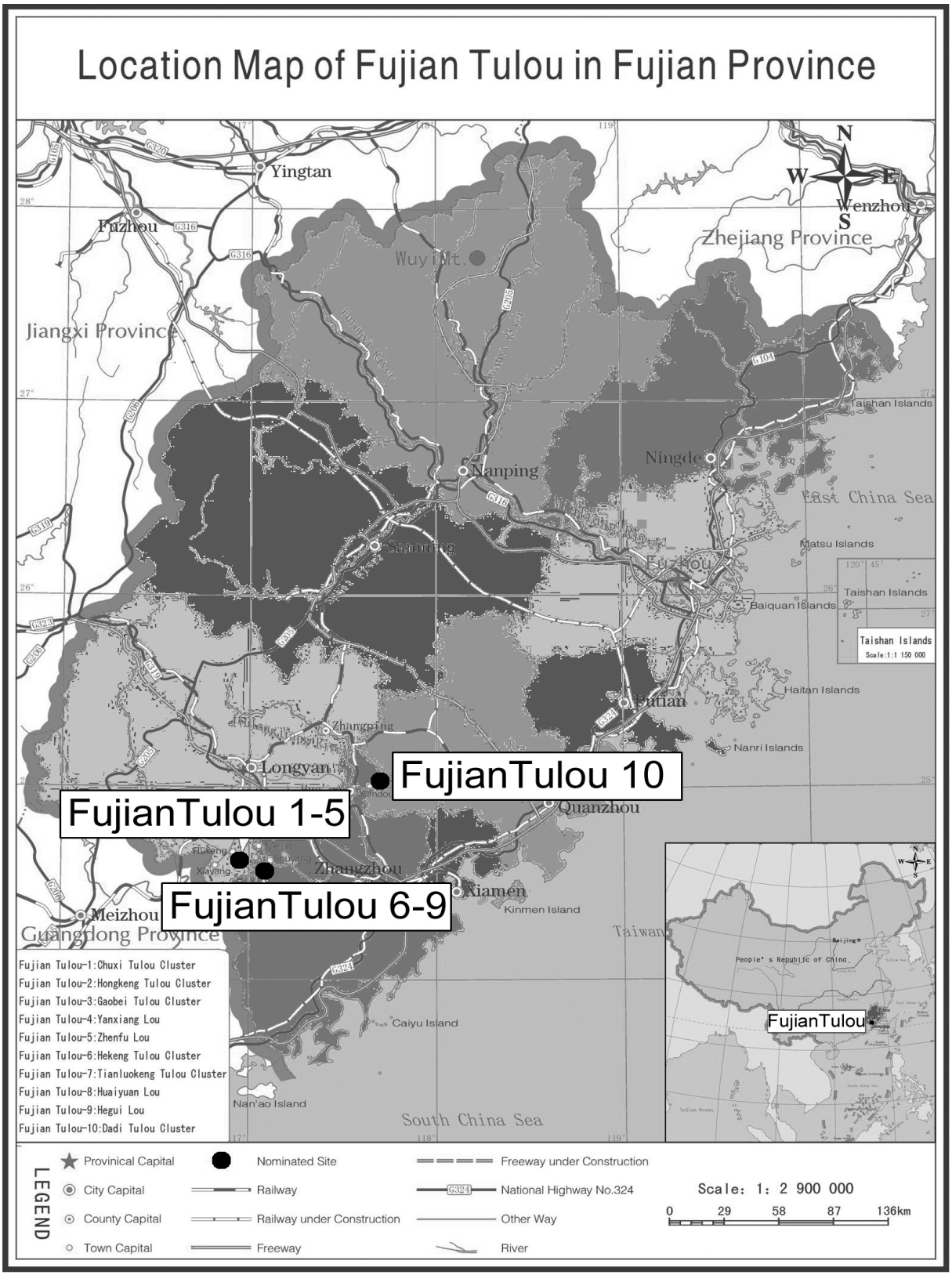


Fig. 1 Location map of Fujian Tulou.
Source: Nomination Documents of Fujian Tulou.

Table 1 Fujian Tulou in the world heritage list.

City	County	Name	Amount of buildings	Serial number
Longyan	Yongding	Chuxi Tulou Cluster	10	1
		Hongkeng Tulou Cluster	7	2
		Gaobei Tulou Cluster	4	3
		Yanxiang Lou	1	4
		Zhengfu Lou	1	5
Zhangzhou	Nanjing	Hekeng Tulou Cluster	13	6
		Tianluokeng Tulou Cluster	5	7
		Huaiyuan Lou	1	8
		Hegui Lou	1	9
	Hua'an	Dadi Tulou Cluster	3	10

farming culture in the mountain areas. The lineage organization keeps its power, unites the community and continues the local culture with the traditional faith of the ancestor worship. The local community plays a key role in the cultural continuity as well as the conservation of heritage, including the intangible traditions, the tangible buildings and their environment.

2. Changes after Nomination

Fujian Tulou was not well-known, and the local community kept their own pace of life, continued with their traditions. However, tourism has brought huge changes in the sites after nomination.

2.1 Tourism Development after Nomination

The title of "world heritage" has always been chased by tourists in and out of China. After nomination in 2008, the number of tourists coming to the heritage sites of Fujian Tulou has increased dramatically (Fig. 4), which promoted the local tourism industries. The heritage tourism revenue has

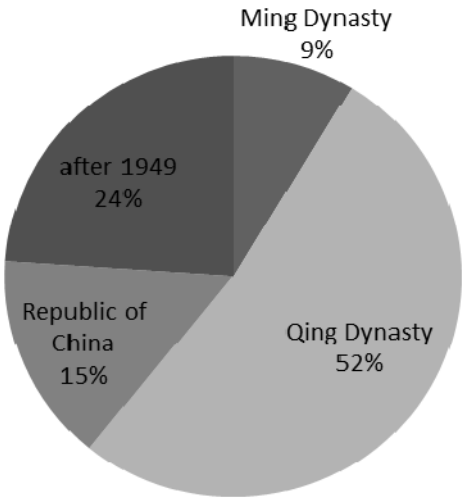


Fig. 2 Nominated buildings of Fujian Tulou in different periods.

(a) Separate entrances and stairs for each family, Yuqing Lou in Chuxi Cluster

(b) Shared corridors of the whole buildings, Shanqing Lou in Chuxi Cluster

Fig. 3 Two different forms of interior space of Tulou (photo by Y. Jia, 2011).

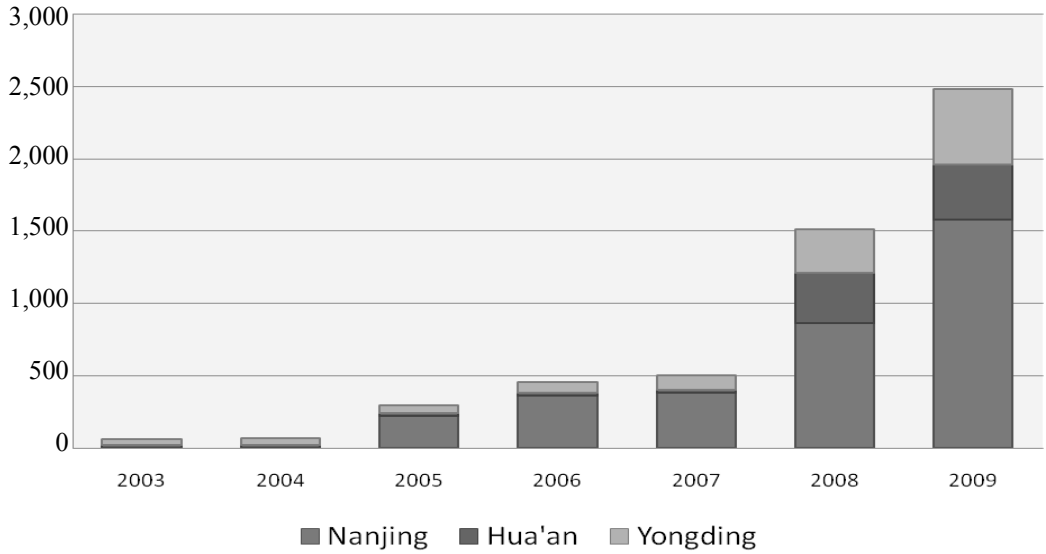


Fig. 4 Tourists to Fujian Tulou in 2003-2009 (thousands of people).
Source: Yongding Bureau of Cultural Relics, Nanjing County Yearbook, Hua'an Bureau of Culture and Sports.

increased and therefore contributed to the local GDP (gross domestic product). For example, the tourism revenue of Nanjing County in 2008 reached nearly four times as the previous year, and was 5.1% of the local GDP, tourism revenue of Hua'an Cluster was over 30 million RMB (around 4.4 million American dollars according to the prevailing exchange rate) in 2009, 65.0% of the county's total revenue [2].

As a favorable factor for the local economy, the tourism is welcomed by the local government. Tourism companies are introduced to the heritage sites to manage the Tulou tourism together with the government and local community.

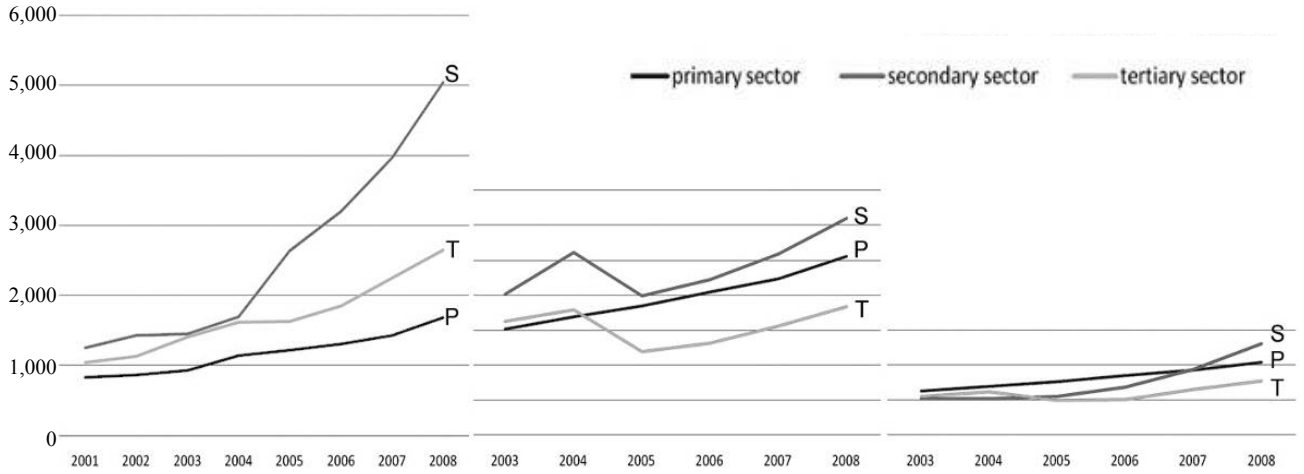
There are three independent management systems in the three counties where situated the nominated buildings. The 23 buildings of five villages or towns in Yongding County are managed by the Bureau of Culture Relics of Yongding Government and the Hakka Tulou Tourism Development Co, Ltd.. The 20 buildings of four villages or towns in Nanjing County are managed by the Site Management Committee, the Bureau of Culture of Nanjing Government and the tourism company. The three buildings in Dadi village in Hua'an County are managed by Municipal Bureau of Culture and Sport of Hua'an Government and the Tourism Development Company [2]. The governments and tourism companies (which also belong to the governments, except the tourism company in Hua'an County) make the major body of the management system, in which lacks the voice of the local community. The result is that it contributes more to the local economic indicators, not to the life of local residents, who is the core community of the heritage [3].

The management systems lead to different effects to the heritage sites, both in heritage conservation (including the intangible aspects) and tourism development, which will be talked in the following part. At the same time, there exist some conflicts between different counties in the tourism competition, especially between Nanjing and Yongding, which are close geographically. It is not good for the regional sustainable development.

2.2 Changes in Local Industry Structure

The local industry structure has been changing, caused by the development of heritage tourism. The tertiary sector (service occupations) has increased a lot and become a large part of the local industry structure in Yongding and Nanjing Counties; while in Hua'an it has no obvious change (Fig. 5).

The local community used to engage in farming,



(a) Yongding County (b) Nanjing County (c) Hua'an County

Fig. 5 Industries changes in Nanjing, Hua'an and Yongding Counties.

Source: Research on Conservation of World Cultural Heritage and Economic Development of Heritage Sites.

supporting their life and shaping their culture. Tea producing was another important industry in the area, which was the main source of income and enriched the local culture as it provided more funds and opportunities to hold cultural events. These traditional industries, together with handicrafts and aquaculture, have been developing throughout the history, paying attention to the nature and getting the harmony between the built and natural environment.

New modes of productions have been developing ever since the society changed. Lots of Chinese in southeast of China went out to South Asia in the end of 19th century and the beginning of 20th century. This is a tradition for the people in Fujian Province. After 1980s, most young people flocked to developed cities in China for work, such as Guangzhou and Shenzhen, and the labor export became the main industry in many places. The dominant role of industry has turned to tourism industries in some places after 2008, but not all sites (Table 2). According to our field work and interviews, the management systems and development plans explain the diverse situations of different sites.

In general, tourism is developing in all sites and has become the dominant industries in the highlights of the sites (Table 3), such as Hongkeng in Yongding County, Changjiao (Huaiyuan Lou and Hegui Lou) and Tianluokeng in Nanjing County. But Yanxiang Lou and Hekeng are two exceptions, the former has no residents living there, and young people all go out in the latter as no local industries could be continued due to the protection requirements of the nominated buildings.

2.3 Changes in Living Way of Local Community

The living way of local community has changed, and it could be seen as a result of the change of local industry structure. The changes differ a lot between sites. For example, there is little change in Dadi Tulou Cluster in Hua'an County and the community still mainly engages in tea producing. To the contrary, in Yongding and Nanjing, the living way changes greatly where new industries like labor export and tourism are booming up (Fig. 6).

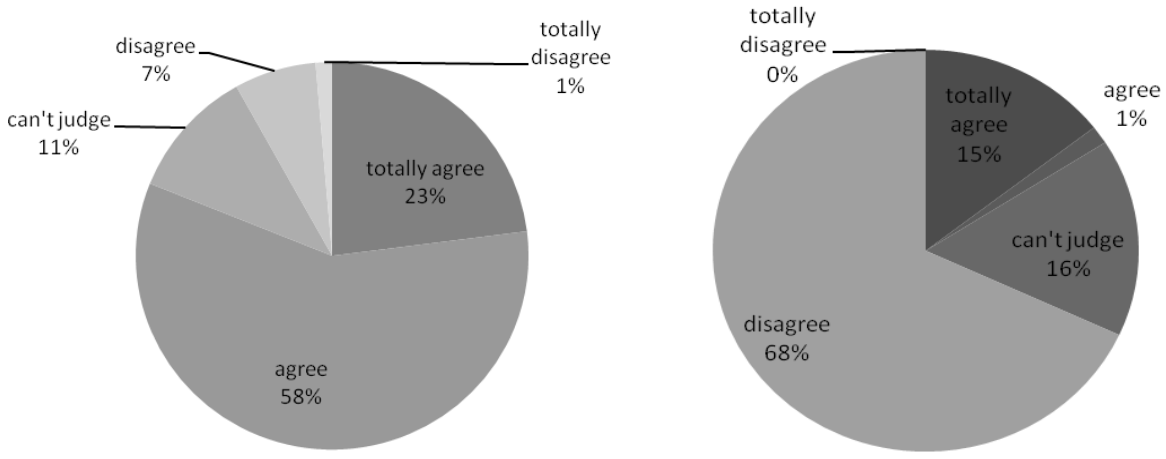
The life changes a lot where tourism becomes the dominant industry. Take Hongkeng and Tianluokeng as examples. The local people used to go out of the town for living, but come back hometown to run some souvenir shops (or stalls), restaurants and inns now. This has brought both positive and passive consequences. For the good thing, more young people stay and have the opportunities to learn the local

Table 2 Industries in the heritage sites of Fujian Tulou.

Industry	Development	Causes
Traditional farming	Declining generally	The local mountainous environment is not quite suitable for farming; the farming does not take full use of labor and its income is low; the farming land is used for tourism or construction for new villages.
Tea producing	Developing in some areas	The local climate and environment is suitable for tea cultivation; there has been mature technology and high acceptance from the market; the income is high; the producing conditions are met in the new villages.
	Stopping in other areas	It needs some funds; some processes of production are forbidden in the nominated buildings but no new buildings to replace the original production space.
Traditional handicraft	Declining generally	The products do not meet the current needs; the traditional crafts are not taken enough notice.
Traditional aquaculture	Declining generally	There are more accesses to the meat in the market economy; it is forbidden in the nominated buildings.
Labor export	Developing rapid in some areas	There are traditions for the locals; there are not enough employments in the local places, with surplus labor; the income is high.
	Declining in other areas	There are more local employments in tourism industries and its income is as high as working outside.
Tourism	Developing generally	It increases the household income; there are some employments in the tourism companies.

Table 3 Dominant industries in the heritage sites of Fujian Tulou.

County	Sites	Dominant industry/industries	Other industries
Yongding	Chuxi (Cluster)	Labor export	Tourism, farming, tea producing
	Hongkeng (Cluster)	Tourism, labor export	Farming, tea producing
	Gaobei (Cluster)	Labor export	Tourism, farming, tea producing
	Yanxiang Lou	Labor export	Farming
	Zhengfu Lou	Labor export	Tourism, farming, tea producing
Nanjing	Hekeng (Cluster)	Labor export	Farming
	Tianluokeng (Cluster)	Tourism	Tea producing, labor export, farming
	Changjiao (Huaiyuan Lou & Hegui Lou)	Tourism, tea producing	Labor export, farming
Hua'an	Dadi (Cluster)	Tea producing	Tourism, farming



(a) Yongding County (b) Hua'an County

Fig. 6 Statistical results from the questionnaire on "Do you think your life style has greatly changed after the world heritage site nomination?".

Source: Research on conservation of world cultural heritage and economic development of heritage sites.

tradition, which was impossible when they were all out, and the sites turn to be more "living". For the not so good, too many souvenir shops or stalls and restaurants give inauthentic feelings to the heritage sites (Fig. 7), not only because they are not coordinating with the heritage buildings, the products they sell lack the local traits, but also because the community now seems to live quite a different life than before.

However, even in the famous sites, the traditional life keeps on parallel with the new tourism industries. We did a statistics of local people's behavior in Hongkeng, where we counted the numbers of people who were engaging in traditional industries such as farming or tea producing and who were engaging in tourism industries, and the result showed that they balanced (Fig. 8).

The heritage tourism has enhanced the cultural identity and proud of the local community, but at the same time lead to inconvenience to their daily life. "Some strangers come into our house" is an often-heard complaint from the local residents, and it causes stealing. As all the sites require an admission tickets to the tourists, people from neighboring villages or towns who want to visit their friends and relatives have difficulties to just walk into the "heritage areas".

The heritage protection has the same "double-edged" problems. All the residents agreed that the protection measures brought improvement in their living conditions, but some activities would no longer be possible in their own houses, for example

Fig. 7 Souvenir stalls in the courtyard of nominated Tulou in Tianluokeng Cluster (photo by Y. Jia, 2011).

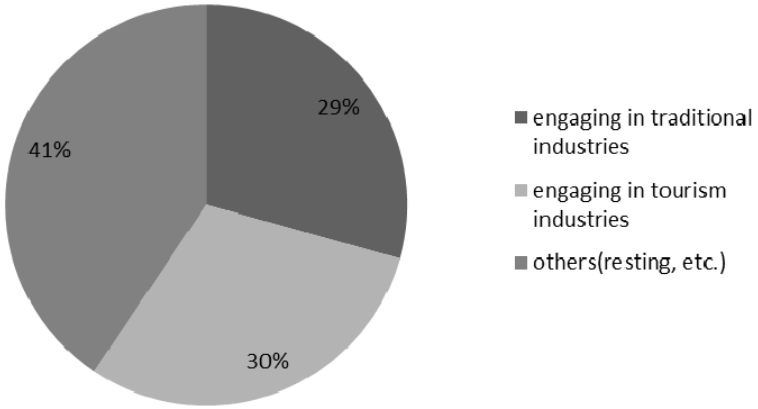


Fig. 8 The amount of people's different behavior.

the tea producing, which might cause damages to the buildings. In Dadi village, new dwellings were built for the tea makers so that they could keep their production and it was also good for the buildings as not too many residents to live in the nominated houses. However, no new residential buildings were built for the residents of Yanxiang Lou and Hekeng Tulou Cluster, where the locals have to go out for a living. They could not produce tea in their houses as it is against the conservation demand. As a result, there are almost no young people in the village and their cultural continuity is facing great crisis. The sites are clean and beautiful (Fig. 9), as a museum, not a living heritage site.

3. Benefit from Tourism for the Local Community

Obviously, the tourism has brought great benefit to local economy indicators, but is there some benefit to the local community?

3.1 Community's Income from Tourism Companies

The admission tickets make a large part of the economic contributions from heritage tourism. The ticket income is obtained by the tourism companies who manage the tourism, build some facilities and offer guided tours. Actually, they utilize the heritage resource and they ought to pay for this to the owners of the heritage—the local community.

The buildings in the heritage sites could be classified into nominated Tulou and non-nominated, whose owners get different income from the tourism companies. For most sites, there are two kinds of income. The rent means the money for the owners of nominated buildings and it is distributed to the household according to the area of the buildings. The resource fee means the money for all the villagers, distributed according to the population. For the sites of clusters where almost all of the buildings are nominated, like Nanluokeng and Hekeng, the rent and the resource fee are similar and paid to each person in the villages. For the single buildings, there might be no resource fee for the villagers. The income distinguishes a lot in different sites (Table 4). All these incomes are fixed except Dadi cluster.

This kind of income is really little when each family gets only 2,000 RMB (about 309.7 American dollars, according to the average exchange rate in 2010, as the data was of the same year) per year for most and they have to bare all the inconvenience from tourism every day. The large part of tourism income comes into the companies, who are not the owner of the heritage. That is how the local think and it is not surprising that there are conflicts between the two.

Fig. 9 Tulou lack of community's living life in Hekeng Cluster (photo by Y. Jia, 2011).

Table 4 The earnings of locals in the heritage sites of Fujian Tulou (the values are calculated into American dollars according to the average exchange rate in 2010, as the data was of the same year).

County	Name	Rent (nominated Tulou)	Resource fee (village)
Yongding	Chuxi Tulou Cluster	￥30 ($4.4) for each room per year (only Yuqing Lou which is used as a museum);	Insurance of ￥2.8 ($0.4) for each person per year
	Hongkeng Tulou Cluster	￥100,000 ($14,772.1) per year for Zhencheng Lou, ￥40,000 ($5,908.9) per year for Fuyu Lou, a couple of thousands per year for other nominated buildings;	￥700-800 ($103.4-118.2) for each person per year (2010)
	Gaobei Tulou Cluster	￥100,000 ($14,772.1) per year for Chengqi Lou, ￥30,000-40,000 ($4,431.6-5,908.9) per year for Shize Lou;	8.3% of the ticket sales (not implemented yet)
	Yanxiang Lou	￥20,000 ($2,954.4) per year;	None
	Zhengfu Lou	￥8,000 ($1,181.8) per year.	None
Nanjing	Hekeng Tulou Cluster	￥22.9 ($3.4) for each room per year	None
	Tianluokeng Tulou Cluster	None	￥150,000 ($22,158.2) per year for the whole village
	Huaiyuan Lou	￥20,000 ($2,954.4) per year	None
	Hegui Lou	￥25,000 ($3,693.0) per year	None
Hua'an	Dadi Tulou Cluster	3.5% of the ticket sales (￥91,000 in 2010, i.e., $13,442.6)	0.5% of the ticket sales (￥13,000 in 2010, i.e. $1,920.3)

3.2 Other Benefits from Tourism

Tourism is welcomed by the local people as other benefits are also brought in, such as the jobs offered by tourism companies and the income from running a family business. According to our interviews, most locals considered tourism as a good way to increase their income.

The owners of nominated buildings could run a small inn which attracts tourists to experience living in Tulou, as well as selling tea and some souvenirs. The residents close to the nominated buildings could run a restaurant which is forbidden in the nominated buildings or an inn with lower price. They might also rent their houses to people from outside of the sites who want to earn a living by selling paintings of Tulou. Others might sell their vegetable to the restaurant runners to get an additional income. The residents from nearby villages and towns could work for the tourism companies or benefit from their own family business as more tourists come and consume.

3.3 Problems in Tourism and Their Solutions

The previous studies show that tourism is an industry depending too much on outside [4]. It is quite seasonal in the cases in China, and the number of tourists surges during the Labor Day's and National Day's holidays. This means tourism industries could not be the sole dominant industry, otherwise there might be social problems. It might happen that the tourism decline generally or suddenly years later when huge quantity of labors would lose their jobs. Other industries, especially the traditional industries, should be encouraged and developed to ensure a steady economy and sustainable society.

Tourism without proper management might harm the spirit of heritage sites. In most sites of Fujian Tulou, there have been too many individual businesses without appropriate forms. Though the stalls are temporary and do not damage the buildings, they do harm the atmosphere. It leads the loss of authenticity. This could be solved by standardizing the souvenir stalls and more importantly, by encouraging the local community to engage in traditional industries, like tea producing, which might reduce the number of sellers.

The lack of regional planning is another existing problem in Fujian Tulou. The management systems of the three counties never thought to cooperate with each other and in fact they are competitors in tourism

service. Even in the same county, there might be conflicts between people of the nominated sites and their neighborhood, where the former consider them as the supposed beneficiary but the latter might get more as they have no restrictions on construction. Harmony only exists in the same village or town, where people live and work together. A regional planning is in emergent need, not only on conservation but also on tourism, so that the benefit could be shared by all the people in and around the heritage sites.

Dadi Cluster sets a good example for other sites. Tea producing is still the dominant industry. The locals would not take tourism for more than normal importance and consider it only as an avocation besides tea producing. The allocation of profit is more fair and actually the community does not care much on how much they get from tourism as they have a more stable and high-income job as a tea planter and producer.

4. Conclusions

Fujian Tulou is a living heritage and the continuity of community's life is very important in conservation. The title of "world heritage" has brought some opportunities, and great changes have taken place after nomination, including the community's life and the industry structure, where the tourism plays a key role. Tourism is a good way to enhance the community's cultural consciousness and improve their living conditions, when cultural exchanges happen in tourism and the individual business increases their income. But it does not happen in all sites of Fujian Tulou.

Obviously, tourism has its advantages in developing the local economic. However, the locals might get little benefit as they are not considered as one of the managers of heritage tourism. At the same time, tourism industries could never replace of the traditional industries to become the sole dominant industry, owing to the inherent weakness. Diverse industries in the local industry structure are indispensable for the heritage sites.

There exist both good and bad situations of local society and heritage conservation in the case of Fujian Tulou. Tourism, as an essential factor to interpret the different results, needs to be properly managed, according to the current development for each site and be included in a master plan integrating all sites.

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Causes of Buildings' Abandonment in the Years 1960-1990

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Abstract: When a relatively new building is not being fully utilized, there must have existed, at one time, a change in its initial conditions. The aim of this research is to study the changes in the initial conditions which cause buildings to be underutilized and analyze whether the demolition was justified. Causes can be found in problems due to the building's management, as the owners make the main decisions concerning the buildings. Additionally problems are due to the location where the building is constructed because site conditions changes a lot in one generation. The use of the building can also be a cause of abandonment as the original use can end before the lifespan of the building. Architectural style can be dated as fashions and styles change rapidly. Finally, causes can be in the physical condition of the buildings: structure, construction, installations and adherence to current regulations. In this article, the authors provide guidelines demonstrating how buildings of a past generation which were initially considered obsolete, can be properly reused.

Key words: Historic architecture, demolition, restoration, upgrade.

1. Introduction

A demolition is a symbol of destruction of something which was in some way ill conceived. The demolition of a building can happen because a building was improperly built, is shameful to see or simply no longer able to serve its initial purpose. When buildings which were built not long ago are either demolished or abandoned it is wise to wonder what caused the building to fall into disuse. Buildings are expected to remain, except those that are grouped under the term ephemeral architecture.

The loss of efficiency or the inability to meet the expectations for which a building was built can cause buildings to be abandoned.

Buildings can be fully or just partially abandoned, partial abandonments leave only a part of the building in disuse. It is also possible that a building is temporarily abandoned until a new use of the building is found to meet its current conditions.

Refurbishment of the twentieth century architecture has aroused an enormous interest in recent years. Although much has been done, there is still much to be done in the field of refurbishment. After contrasting experiences and achievements, we have become aware of the importance the heritage has referring to this architecture. Most of the literature we refer to highlights the idea that the conservation of the architectural heritage of the twentieth century is a difficult but necessary task [1].

The possible causes for the problems which provoke the neglect of a building can be classified into five different groups. In many cases the abandonment of a building results from a combination of reasons belonging to different groups.

2. Problems Due to Heritage Management

Issues related to the property and to the management of heritage are decisive in the destiny of a building since its owners are the ones who are in control of those

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decisions.

Buildings can have different owners throughout their lives as they are economic assets which can be profitable depending on how the property is managed. Any change stemming from the goals of property owners can have, in what refers to how to use the building, a decisive impact on the life of a building, no matter their architectural qualities.

There are other economic reasons. Maintenance of a building can be very costly and can render investments unprofitable. Furthermore, changes in the urban planning of the surrounding area can change the conditions for maintaining the building in a specific site.

Sometimes it is much more convenient to allow an abandoned building to fall into ruin before building a new one in its site. Therefore, we firmly believe that the criteria which make a building profitable should determine whether or not a building is continued to be used or abandoned.

The corporate headquarters of the car manufacture Seat in Madrid and Barcelona were located in buildings which were deeply linked to what the enterprise represented in Spain in 1960s. The evolution of the company was a fundamental factor in the evolution of these buildings. This is the reason why they have not survived after the original seat factory disappeared. They were never completely abandoned and only partially demolished, however, their original image has been removed. These buildings were the result of an architecture that was the image and representation of the emerging technological development of Spain in those years, and of a dictatorial political system eager to turn Spain into an industrialized country and consolidate relationships with foreign countries [2].

Buildings such as the Bank of Spain in Gerona and Jaén were abandoned after the part the state central banks play declined since their functions were absorbed by the European Union. The closing down of most premises all over Spain was at its height in 2002 [3].

There are also buildings which are abandoned before being finished. Apart from the illegal constructions which are obviously paralyzed, there are also promotions in which the housing demand does not meet the previous expectations. Economic crises also disrupt the construction process due to the lack of funds to continue with it or the lack of prospective buyers.

In general, we can say that the management of heritage suffers from instability due to different reasons, profit being one of the most important ones. As a consequence of poor management a building can cease to be profitable before the building begins to deteriorate.

3. Problems Due to Location

The location, the physical space where the building is constructed, can undergo a dramatic change which can create problems or, at least, not fulfill the conditions under which the building was built. Site conditions can vary enormously in just one generation. Most of the buildings of a past generation, according to the urban development of the 1960s, are currently located in areas that there are favorable to speculation. Speculation will certainly make demolition more likely. On the other hand, it can also create new lucrative possibilities.

There are examples of central locations which were once important but have since lost their significance, like Plaza de España in Madrid, where, currently, are numerous buildings which have been abandoned. This begs a question whether the influence of the site has played an important part in the abandonment of the buildings especially given they are not only representative buildings but are also ones that are in good condition. A priori, the site does not seem to have suffered a dramatic change that might have led to the abandonment of the buildings, but it should be considered that the abandonment of the first building had a spillover effect which provoked the abandonment of other buildings.

When industrial districts are incorporated into the

city centre, they cannot longer maintain their original status. This is what has happened to central markets and docks in some cities. Some examples are the docks in Lisbon and Oporto, Les Halles in Paris and El Matadero (slaughterhouse) in Madrid.

There are other situations which can be far more dramatic but, fortunately, they are very rare. Cities and entire villages have been abandoned for different reasons always related to the area where they were built. There are some examples of populations who had to migrate when the industrial holdings they were working for closed down. This has happened areas with mines, ports, quarries and oil fields. Other reasons for abandoning a place can be due to geographic instability caused by natural disasters or wars.

The neighborhood of Varosha, a famous resort in the town of Famagusta in Cyprus was completely abandoned after the Greek-Turkish conflict in 1974. Its location near the new borderland made its reoccupation impossible and its buildings were abandoned long ago [4].

Another example is the city of Pripyat in Ukraine, which was evacuated after the accident that took place in the nuclear power plant in Chernobyl in 1986.

4. Problems Due to Changes in Possible Uses

In many cases, during the design process before a building is constructed, its potential use becomes obsolete. The use of a building is variable thus subordinating the survival of a building to its use may compromise the building itself and put an end to it long before the life span of a building.

In the cases mentioned above, the survival of a building can be viable if the building can be assigned a different use. The success of restoration may depend on the building's capacity for serving new uses which do not require changing the fundamental structure as buildings outlast their uses.

Moreover, it is unlikely that a building will only serve the use it was originally intended for. Buildings are, in some way, living creatures and their adaptability is one of their main features. Society evolves, needs change and adaptation, mutation and natural selection are all facts of life which can occur if change is not prevented.

Residential housing is, however, an exception due to its permanent features. There have been very few changes in what people require from their homes throughout time. So these buildings can be easily adapted to new situations as long as the use does not vary excessively. We can find lots of examples of buildings from past centuries which are still in very good condition and are being used for the purpose they were projected.

Buildings constructed for temporary exhibitions and events, for example, the Olympic Games, are not fully utilized after the event.

So far there has been a policy of finding subsequent uses for the building after the event is over. Many of the buildings created for the Olympics in 1992 in Barcelona were successfully reused afterwards. A part of the city which was an abandoned industrial area was turned into a residential area which opened the city to the sea. What was originally the residential housing for Olympians became a permanent residential area.

However, reusing buildings as they did in Barcelona has not always been successful. The facilities built in Valencia for the American Cup, the pavilions for the Expo 92 in Seville, the water tower in Zaragoza and the Olympics in Athens in 2004 were abandoned, and are examples of unsuccessful attempts to reuse the facilities. The cost of maintenance is so high that neither the municipality of Athens nor the Greek government can afford to spend a single euro towards its conservation and use. The facilities built for the Olympics in Beijing in 2008 seem to suffer from the same fate.

These previous experiences made the London local government take other measures for the 2012 Olympic Games. Very few of the facilities were built to outlast the event and those built to last a long time have or will be reused. The shooting center designed by the Plasma

architectural firm will be reused in Glasgow for the Commonwealth Games in 2014. The basketball court of Wilkinson Eyre could also be reused in the 2016 Rio de Janeiro Olympic Games.

This is a different approach to the one based on investing a lot of money in facilities whose aim is to be reused in a near future. This approach is more pragmatic and less costly as its aim is not to leave any building or facility unoccupied when the event is over. This new approach is in line with the current economic and social reality which supports a much more responsible and civic investment [5].

A special issue refers to hospital uses. Buildings such as leper houses, psychiatric and nursing homes which are no longer in use, are usually neglected and rejected as if they were under an evil spell.

The industrial use of buildings is one which has been through severe changes throughout history. By nature, industry is a fast moving activity closely related to the site. Industries deteriorate, change their ownership or their objectives, move to a different site or simply disappear. Therefore, those buildings which cannot adapt themselves to a different use are unlikely to survive the ups and downs of industry. Detroit, for example, has a record number of abandoned buildings. The crisis in the car industry has made that many people and businesses have fled from the city. The exodus has not only affected working class neighborhoods but also the commercial centers.

Other buildings which are frequently abandoned are those related to transportation. Railway stations and tracks which are no longer in use leave a considerable amount of buildings which have proven difficult to be reused. The Subbética railway track in Andalucía, Spain, is a sensible example of how what was once a railway track can be used for tourism. The abandoned track has become a path for cyclists and the former stations have turned into restaurants and inns. Unfortunately, this is an exception among the distressing scene of abandoned stations you can find all over the world.

This distress can equally apply to gas stations which have been abandoned as a consequence of diverting the course of the road in which they were located after a new plan has been carried out.

The airports and railway stations located close to the city center cannot be enlarged cease to function properly because they cannot adapt themselves to heavier traffic or allow the take-offs and landings of modern aircrafts in the case of airports. Reusing them is difficult but possible. We can find significant examples in the city of Berlin, in which the former Tempelhof Airport, closed in 2008, has been used as a public park in the city since 2010. Also in this same city the former Hamburger Bahnhof railway station was renovated in 1984 becoming a museum of contemporary art.

Industrial facilities linked to ports that have changed their location as they cannot grow and accommodate larger vessels, are also abandoned but it is possible to reuse them. One of the finest examples is Chelsea, a neighborhood in New York, which has become one of the trendiest areas in the city.

It is obvious that the most remarkable buildings of a certain period cannot be neglected. A possible use can be turning them into museums of themselves. Unfortunately, this lofty fate is only reserved for the most outstanding buildings. Second rate buildings will have to preserve their existence by seeking a new use.

5. Problems Due to Aesthetic Conditions

This is a third group that is more difficult to analyze and define. Problems due to aesthetic issues, or issues related to changes in the architectural style of the time are difficult to predict.

It is perhaps in the aesthetic aspects of the building where the need for renovation is most necessary. There are fashions and styles that change rapidly and are increasingly important to the image of the building. These buildings belong to a period in which the prevailing culture is one of consumption and rapid disposal.

Now that we are in a period which rejects this culture,

you need to understand the values that led to the project and its original construction to know whether the building needs to be renovated or just remodeled.

Architecture embodies values, laws, intelligence, beauty, character, spirit and substance amassed over time. It is sometimes admired, sometimes ignored and often despised, and consequently enlarged, preserved or degraded for a continuous indefinite period of time. Each intervention further abandons the building's best condition: that which reveals its most genuine qualities [6].

It is, therefore, necessary to find out the potential within this architecture to give it new life while also attending to its original image.

We are in a period of time in which a lot of effort has been put in preserving our heritage yet we are in a society that continually produces objects, ideas, cultural products not intended to continue forever but instead to be replaced quickly. The coexistence of these terms is difficult. However, cataloging twentieth century heritage that has been undertaken either with degrees of protection or of cultural interest, has permitted the successful renovation of outstanding examples of modern architecture which would have been lost otherwise. It also shows that these buildings have life beyond the originally scheduled.

We cannot ignore the difficulty of assessing the architecture of a past generation. The architecture which corresponds to the years 1960-1990 is the architecture of our parents which has to be denied in order to grow. It does not have the charm older architecture has for us. It is not old enough but simply out of fashion. Formal or stylistic obsolescence of a building may soon end long before its life and can make it appear ugly and degraded.

In the same manner, a car needs to be "restyled" or redesigned, architecture may need an updated image. This is not an exercise aimed at changing the facade but rather at altering the whole building and its elements, being the installations such as lightning, plumbing, partitions, interior design the most affected ones. In some way, the building should be redressed and given a new presentation to the public.

The administrative centre of Pantin turned into the National Dance Center of Paris [7] is an example of a reconstruction that has been able to provide the building with a new more attractive image while maintaining the best qualities of its original form (Fig. 1).

It is very rare for a building to be protected within the same generation of when it was built. It appears to take time for a building to have its value recognized. Sometimes protection is late and the damage is irreversible. There are exceptions: the building known as the crown of thorns of Fernando Higueras and Antonio Miró was the first to be declared of National Cultural importance in Spain while its designers were still alive [8].

Fig. 1 National dance center of Paris.

6. Problems Due to Technical Issues

This section focuses on the physical condition of buildings: structure, construction, installations and adherence to current regulations.

The object of this architectural article focuses on buildings built in the years 1960-1990 which are in most cases structurally unsound. Today's contrasting and well perfected techniques are the result of the developed modern heritage movement. The current time period is a time when the industry standards call for improved materials and tight quality control.

The structures are in general large and allow for easy changes in distribution. These structures tend to be durable and safe. The standards for building sound structures have changed little in a past generation, they do not need to be readapted in such a way which requires vast changes to meet new standards and quality controls which would render the reconstruction economically unprofitable. Such an example is the Hotel Ryugyong in North Korea. Its construction began in 1987, in response to the construction of another hotel built in Singapore by a company from South Korea, a nearby rival emerging economy. Certain complications, which resulted from the use of improper materials and poor architectural techniques, deemed the building too costly and it was thus abandoned in 1992 [9].

There are faulty buildings during this period but such buildings are the exception. The Piraeus Tower in the capital port city of Greece, was abandoned in 1983 before it was finished due to structural problems resulting from errors made during its construction. Concrete structures built in Spain between 1950 and 1980 with degenerated cement under certain atmospheric conditions at the time of discharge, may have resulted in Aluminosis, a serious pathology, which forced the owners of the buildings to demolish the buildings affected.

The structures built between 1960 and 1990 are generally durable and well supported. The nearly blind experimentation and precarious methods of the past generation evolved into a more developed and tested construction thanks to technical advances. It could be said, for example, that flat roofs no longer produce leaks and curtains walls have no isolation problems. There is at this time a slight predominance of lightweight, easily adaptable facades in which, a priori, constructive solutions should be kept instead of exchanging them for another skin.

Facilities have advanced significantly since the last generation. Today's needs are far more complex, and so are our resources. The percentage of the budget dedicated to facilities since the last generation has increased from 15% to 30%, and to 60% [10].

Antiquated facilities which need to be updated are very common. The standards of environmental conditioning and comfort have grown very rapidly and few buildings of a past generation adhere to current standards. Updating facilities is generally feasible, buildings which were built to be more easily modified at the time of their construction can be readily adapted to current conditions.

Anti fire regulations pose the most difficult obstacle in updating old buildings to fit current regulations. The case of the Windsor building in Madrid which went up in flames during the renovation process and had to be subsequently demolished, speaks to the need to update buildings to adhere to current anti-fire regulations. Such updates need to be made before it was too late.

7. Conclusions

Function follows form (and vice versa): Abandoned buildings can be recovered. The romanticism of ruin inspires the glory of rebirth. The buildings were born to be useful and beautiful and all possibilities should be explored. In this light, modern modifications offer new opportunities for productive renovation. The potential of buildings generally remains partially latent. It is said that the famous sentence by Louis Sullivan, "form follows function" is restrictive and does not correspond with the current situation.

The documentation and knowledge of the building

are important for the purpose of renovation. It seems clear that modern architecture cannot be treated as ancient monuments are. Buildings are not conceived to serve as monuments but as structures which respond to specific useful functions. When it comes time to renovate a building the restoration process must depart from the classical or generic process of reconstruction and focus on the building specific attributes.

From this it follows that buildings with clear spaces can be more easily renovated to fit modern standards. A building with adaptable structures will be more likely to be adapted to different uses in order to live up to its full potential for a longer period of time.

Architects should consider the long term benefit of a building which can readily be altered to fulfill many purposes. For this reason, a building's structure should have few superfluous parts and the facilities and facades should be as independent from the structure as possible. If this is done the building can be far more easily modified. This does not imply that architects should design buildings as generic containers but they should try to avoid adding insignificant details to a building which may deem future modifications less feasible.

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